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Modality and Morphology: What We Write May Not Be What We Say

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Abstract

Written language is an evolutionarily recent human invention; consequently, its neural substrates cannot be determined by the genetic code. How, then, does the brain incorporate skills of this type? One possibility is that written language is dependent on evolutionarily older skills, such as spoken language; another is that dedicated substrates develop with expertise. If written language does depend on spoken language, then acquired deficits of spoken and written language should necessarily co-occur. Alternatively, if at least some substrates are dedicated to written language, such deficits may doubly dissociate. We report on 5 individuals with aphasia, documenting a double dissociation in which the production of affixes (e.g., the *-ing* in *jumping*) is disrupted in writing but not speaking or vice versa. The findings reveal that written- and spoken-language systems are considerably independent from the standpoint of morpho-orthographic operations. Understanding this independence of the orthographic system in adults has implications for the education and rehabilitation of people with written-language deficits.

Keywords

language, psycholinguistics, cognitive neuroscience

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The neurologist Hermon Gordinier (1903) began his presentation for the Annual Meeting of the New York State Medical Society as follows: “No subject in neurology has attracted more attention or excited more discussion than agraphia . . .” (p. 90). Given the scant research on written language production over much of the past century, one might wonder about this great interest in writing deficits. The reason was that neurologists (the cognitive and neural scientists of the time) understood that written language, as a recent human invention, could not be instantiated in the brain in dedicated neural circuitry on the basis of the genetic blueprint. Therefore, agraphia provided an important opportunity to investigate whether (a) these functions are necessarily coinstantiated with evolutionarily older functions (e.g., spoken language, motor skills, or visual skills) or (b) instead, the human brain does instantiate recently acquired neural functions in dedicated neural substrates. They assumed that if written language skills are intrinsically dependent on language or motor substrates, they should not dissociate from spoken or motor skills under conditions of neural injury—hence their interest in agraphia and its relationship to language and motor deficits.

The relationship between the neural substrates that support writing compared with those that support language and action can be considered along a continuum from peripheral motor levels of processing to relatively more abstract morphological, syntactic, and semantic levels of processing. Until the early 20th century, the focus was largely on the motor aspects; the giants of neurology—including Wernicke, Lichtheim, Hughlings Jackson, Dejerine, Charcot, and Exner—heatedly debated whether speech and writing shared the same or distinct cortical centers in the frontal lobe. In this article, we consider the role of language modality at high levels of language processing, specifically examining morphological processing. We report on a set of people with

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cognitive neuropsychological deficits who exhibited greater disruption of morphological processes in writing than in speech or vice versa. The findings reveal a brain that can neurally instantiate novel cognitive functions, such as written language, with considerable independence from the evolutionarily older functions and substrates from which they are likely to have originated. For written language, this independence is not limited to sensorimotor levels; rather, it extends to higher levels of language representation.

The relationship between written and spoken language has been most studied in the context of phonological recoding in *reading*. Researchers have investigated whether written forms are necessarily converted to phonological forms before comprehension. The preponderance of findings has shown that although phonological forms are activated automatically during reading (e.g., Rastle & Brysbaert, 2006), phonological recoding is not strictly necessary for comprehension in literate adults—at least not for single words (e.g., Coltheart & Coltheart, 1997). A complementary question in written word production considers whether access to the phonological form is necessary for retrieving a word's spelling. Here also, the psycholinguistic evidence indicates that spoken forms are often active during spelling and may influence spelling performance. For example, studies have found that when people try to write a word, the simultaneous presentation of a distractor word with a similar sound and spelling results in faster writing times (relative to an unrelated distractor) than does a distractor word with only similar spelling. Moreover, the presentation of a distractor with only a similar sound also results in faster writing times relative to an unrelated distractor word (Qu, Damian, Zhang, & Zhu, 2011; Zhang & Damian, 2010). However, as Damian and his colleagues note, the results do not imply that the phonological activation is necessary for accurate spelling of single words.

In this regard, the cognitive neuropsychological data are especially relevant because they can provide evidence regarding whether a specific process is required for a particular task. Rapp, Benzing, and Caramazza (1997) described a brain-damaged individual who, when presented with a picture of a comb, for example, could correctly write *comb* but might speak a semantically related word (e.g., *brush*). This finding indicates that the conceptual or semantic system can make direct contact with correct word spellings, even if it fails to access the correct spoken word forms; hence, phonological mediation is not necessarily required in written word production. A number of such cases have been reported, involving not only opaque languages such as English and Chinese (Bub & Kertesz, 1982; Caramazza & Hillis, 1990; Hanley & McDonnell, 1997; Hier & Mohr, 1977; Kemmerer, Tranel, & Manzel, 2005; Law, Wong, & Kong, 2006), but also highly transparent languages such as Spanish, Italian, and Welsh (Cuetos & Labos, 2001; Miceli, Benvegnu, Capasso, & Caramazza, 1997; Tainturier, Moreaud, David, Leek, & Pellat, 2001). In addition, the performance of neurologically intact individuals provides converging evidence. For example, Bonin, Fayol, and Peereman (1998) found that priming conditions that facilitate spoken word production do not necessarily facilitate their written production. Damian, Dorjee, and Stadthagen-Gonzalez (2011; Experiment 2) found that under certain conditions, phonological information may not be active during writing. In sum, phonological information may often be active and influential during spelling, but this information is present in the context of a system that also allows for independent orthographic processing.

These findings of orthographic independence do not specifically address the question of the linguistic richness of orthographic processes or representations. The question remains: Are orthographic processes limited to the retrieval of the letter strings that form word spellings or are other aspects of language knowledge available and operational within the orthographic system? Cognitive neuropsychological findings have revealed that spelling processes are sensitive to grammatical category. For example, one grammatical category (verbs) may be more disrupted in writing than in speaking (Caramazza & Hillis, 1991; Hillis, Rapp, & Caramazza, 1999; Rapp & Caramazza, 1998), or people may exhibit contrasting difficulties with nouns and verbs in writing and speaking (Caramazza & Hillis, 1990; Rapp & Caramazza, 2002). The finding that the same pattern is not observed in both writing and speaking indicates that the orthographic system can independently represent an abstract linguistic property such as grammatical category.

Grammatical category is used by morphological processes in constraining possible word forms, which allows English nouns (e.g., *shirt*) to bear the suffix *-s* (*shirts*) but not the suffix *-ed* (**shirted*). This constraint, along with the evidence of grammatical-category representation in the orthographic system, prompts the question of whether morphological representation or processing occurs within the orthographic system. The plausibility of *morpho-orthography* is supported by the observation that word spellings (e.g., in English) are productively conditioned by their morphological structure. For example, when verb stems ending in *e* combine with vowel-initial suffixes, the *e* is dropped (*love* → *loving, lover; animate* → *animation, animator*). Although these operations are analogous to morphophonological processes, they are specifically expressed over orthographic elements and are thus distinctly orthographic. However, clear-cut conclusions do not necessarily follow from these regularities,

Table 1. Information About the Research Participants

Characteristic	A. E. S.	D. H. Y.	K. S. R.	P. W.	V. B. R.
Sex	Female	Male	Male	Male	Female
Handedness	Ambidextrous	Right	Right	Right	Right
Education (years)	18	16	18	12.2	12
Employment before stroke	Manager of federal agency	Banker	Ph.D. student in engineering	Grocery manager	President of family company
Age at stroke (years)	42	35	44	51	51
Research onset (time after stroke)	8 years	2 years	6 months	1 year	5 years
Location of lesion in left hemisphere of brain	IFG, MFG, STG, SMG, AG	IFG, PCG, SMG, antAG, STG	IFG, STG, MTG, ITG, SMG, AG, PCG, PrCG	IFG, MFG, PrCG	IFG, PrCG, PCG, antAG, SMG, IC

Note: IFG = inferior frontal gyrus; MFG = middle frontal gyrus; STG = superior temporal gyrus; SMG = supramarginal gyrus; AG = angular gyrus; PCG = postcentral gyrus; antAG = anterior angular gyrus; MTG = middle temporal gyrus; ITG = inferior temporal gyrus; PrCG = precentral gyrus; IC = insular cortex.

because they might simply represent a limited set of explicitly formulated rules, or their productivity might be due to types of lexical analogy posited in phonology (Bybee, 1995).

The morpho-orthography hypothesis proposes a word-production system in which (in addition to abstract or amodal semantic, syntactic and morphosyntactic operations) morphophonological and morpho-orthographic processes would operate over modality-specific, morphologically complex representations. Alternatively, morphological processes could be limited to the spoken production system with an orthographic system that is "blind" to these linguistic properties. In such a system, although lexical phonological representations would be morphologically complex, lexical orthographic processes would operate over ordered letter strings that are not morphologically structured. Cognitive neuropsychological evidence can contribute to adjudicating between these hypotheses. The morpho-orthographic hypothesis predicts the possibility of morphological deficits affecting one modality but not the other, whereas the alternative hypothesis predicts that morphological deficits should not occur in the orthographic modality alone.

We report on 4 individuals who exhibited specific difficulties (deletion errors, substitution errors, or both) in writing inflectional morphemes. These deficits contrasted markedly with their largely spared spoken production of the same structures. We also report on 1 individual who exhibited the opposite pattern (i.e., difficulties in speaking but not in writing). In addition to documenting the double dissociation of inflectional morpheme production across speech and writing, we also rule out alternative accounts of the data, establishing that the observed inflectional errors cannot be attributed to difficulties in producing word-final segments or explained as lexical substitutions. We conclude that the evidence reveals an orthographic system with high-level linguistic properties that can operate with considerable cognitive and neural independence from the spoken language system.

Participants

All testing was approved by the Johns Hopkins University institutional review board, and participants were paid for taking part in the research. All 5 participants experienced language deficits after suffering left-hemisphere strokes. Although some information is summarized in Table 1, detailed descriptions are included in previous reports focusing on other aspects of their language deficits (A. E. S.—Fischer-Baum & Rapp, 2012; D. H. Y.—Buchwald & Rapp, 2009; K. S. R.—Rapp & Caramazza, 2002; P. W.—Rapp et al., 1997; V. B. R.—Buchwald, Rapp, & Stone, 2007). The 5 participants were identified for this study over a 15-year period because their performance on a screening test for spoken and written sentence production indicated greater difficulty producing inflections in one output modality. Because of the long data-collection period, some task choices changed over time (e.g., as seen later for the word-comprehension assessment).

The participants had different degrees of speech impairment. However, these difficulties did not prevent them from spontaneously producing simple sentences that were both intelligible and communicatively successful. The only exception was V. B. R., whose speech was essentially reduced to single-word utterances. Word writing was also impaired to various degrees across participants, and the spelling of nonwords was severely impaired in all participants. Note, however, that all participants scored within the normal range on single-word comprehension tasks, a strong indicator of intact word semantics. A. E. S., D. H. Y., and V. B. R. were evaluated with the Peabody Picture Vocabulary Test-Revised (Dunn & Dunn, 1981) and scored at the 58th, 87th, and 75th percentiles, respectively. K. S. R. was evaluated with a written synonym-judgment task (concrete words), and P. W. was evaluated with a picture-word verification task. They scored 100% and 95% for accuracy, respectively.

Method

Verb elicitation

For all participants except V. B. R., verbs were elicited by showing pictures of simple events and asking participants to produce single sentences to describe the depicted events (e.g., “A horse is jumping a fence”). The same pictures were used for eliciting spoken and written sentences; we used 89 pictures with K. S. R., 154 with P. W., 59 with D. H. Y., and 77 with A. E. S. The number of trials varied across participants because the number of items in the sentence-production test changed over time and, for some of the participants, was also affected by the individual’s testing availability. Because V. B. R. had great difficulty in speaking whole sentences, her two elicitation tasks required her to name only the appropriately inflected verb; each task was used for both spoken and written elicitation. For the picture-based elicitation task, V. B. R. was presented with a picture of an action with the written label “Today he, . . .” or “Yesterday he, . . .” and was asked to complete the sentence with the appropriately inflected verb (e.g., “jumped”; n = 99 sentences). For the second task, V. B. R. produced written or spoken inflected verbs in response to spoken prompts from the experimenter (e.g., “Today he walks, yesterday he also . . .”; “She jumps, they also . . .”; n = 191 sentences). For both tasks, spoken and written responses were obtained in different testing sessions.

Noun elicitation

Nouns were elicited showing pictures of single or multiple objects to A. E. S., P. W., and V. B. R., who were instructed to speak or write the name of each object and its number (e.g., *one cat*, *three cats*). Pretesting showed that quantities were correctly identified by the participants, so any inflectional errors observed were not due to quantity confusions.

Analysis was restricted to regularly inflected nouns and verbs. When verbs were produced with auxiliaries (e.g., the *is* in *is moving*), only the main verb was analyzed. The analysis considered whether verbs and nouns were produced with correct inflections. Inflectional errors consisted of either omitted inflections (e.g., when shown a picture of two cats, the participant responded *two cat*) or incorrect inflections (e.g., when shown a picture of a boy catching a ball, the participant responded *is catches*). Because the picture-based elicitation task used with A. E. S., D. H. Y., K. S. R., and P. W. was somewhat open ended and allowed for variability in the length and complexity of sentences produced, the number of verb responses varied across output modality and participants. Combining the two elicitation tasks, we examined 89 spoken verbs and 88 written verbs with A. E. S., 65 spoken and 63 written with D. H. Y., 95 spoken and 87 written with K. S. R., 178 spoken and 112 written with P. W., and 280 spoken and 290 written with V. B. R. Equal numbers of nouns were analyzed across the two modalities; we examined 64 nouns with A. E. S., 60 with P. W., and 98 with V. B. R.

Results

The results reveal clear-cut dissociations in inflectional accuracy across spoken and written modalities for both verb and noun inflections (Fig. 1 and Table 2). Inflections were produced significantly more accurately by A. E. S., D. H. Y., K. S. R., and P. W. in spoken responses than in written responses, with effect sizes ranging from 16.4% to 57.9%. These individuals were highly accurate in producing inflections in the spoken modality: Accuracy ranged from 92% to 100%. In contrast, V. B. R. showed the opposite pattern, producing inflections significantly more accurately in written responses (97%) than in spoken responses (42%).

In writing, inflection omissions formed the majority of the written inflectional errors produced for both verbs and nouns (A. E. S.: 17 of 25, 68%; D. H. Y.: 30 of 30, 100%; K. S. R.: 11 of 17, 64%; P. W.: 101 of 107, 94%), although affix substitutions were also observed for all 4 of these individuals (K. S. R.: *slicing* → *slices*; P. W.: *drives* → *driver*; A. E. S.: *perplexed* → *perplexes*). A similar pattern was observed for V. B. R., whose spoken inflectional errors consisted of 59% (94 of 158) inflection deletions (*two shirts* → *two shirt*); the remaining errors consisted of inflection substitutions (e.g., *reached* → *reaching*). We also note that the difficulties in producing inflections in the affected modality were not observed on the stems of the same responses. Other than minor articulatory (*skiing* → /sliɪŋ/) or spelling errors (*palette* → *pallette*), the rate of lexical-substitution errors was very low (4% for A. E. S., 2% for D. H. Y., 13% for P. W., 10% for K. S. R., and 8% for V. B. R.).

The results reveal clear and striking dissociations in the production of inflections across spoken and written output modalities. The fact that inflectional morphology was correctly produced in one modality allows us to infer that high-level amodal semantic, syntactic, and morphological processes were intact and that the difficulties arose at a modality-specific level. However, before we conclude that the findings did, in fact, reflect modality-specific differences in morphological processing, we need to evaluate two alternative hypotheses: that the apparent inflectional errors were due to particular difficulties with word-final

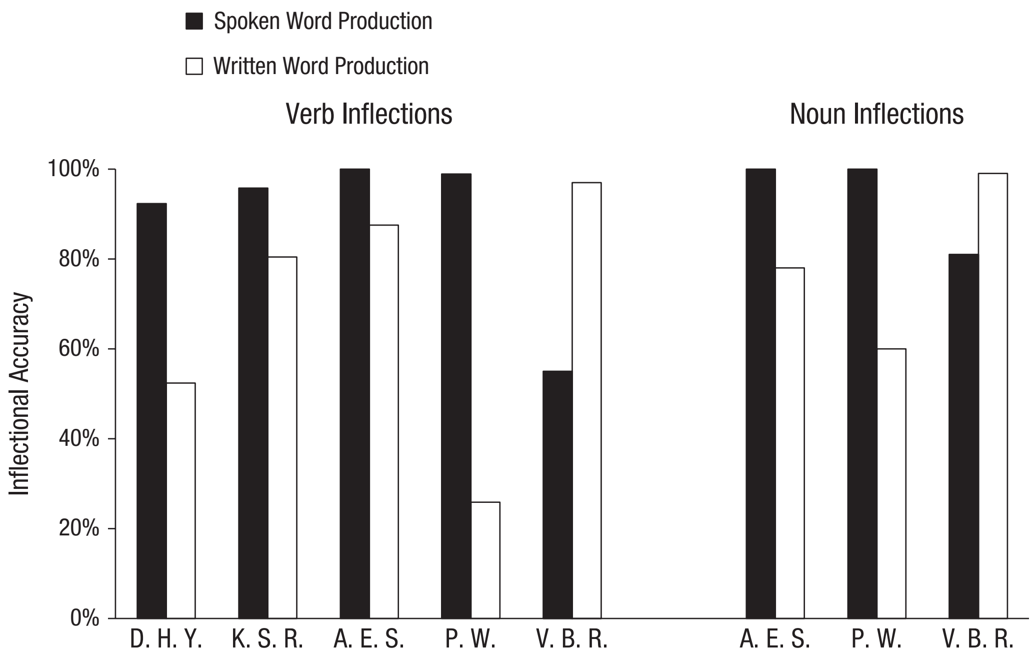

Fig. 1. Participants' accuracy with verb inflections (left) and noun inflections (right) in spoken and written production. See Table 2 for the statistical evaluation of these data.

segments (*word-final hypothesis*) or that these errors corresponded simply to the mis-selection of formal lexical neighbors of the target words during lexical retrieval (*lexical-neighbor hypothesis*).

Analysis 1: Word-position errors?

Cases have been reported with higher error rates in final positions than in initial positions in writing (e.g., Costa, Fischer-Baum, Capasso, Miceli, & Rapp, 2011; Schiller, Greenhall, Shelton, & Caramazza, 2001; Ward & Romani, 1998) as well as speaking (e.g., Olson, Romani, & Halloran, 2007). Could greater vulnerability of word-final positions explain the inflectional errors observed here? This hypothesis predicts that errors should increase toward word endings not only in inflected words (*carts*) but also in monomorphemic words of comparable length (*trust*).

A Monte Carlo analysis was carried out to compare the positional-error probabilities for inflected and monomorphemic errors. We examined only responses from the modality in which participants produced inflections less accurately, and we excluded responses with semantic errors on the stems (e.g., *pulling* → *lifting*). Thirty-two multimorphemic words were analyzed for A. E. S., 29 for D. H. Y., 20 for K. S. R., 94 for P. W., and 398 for V. B. R. Monomorphemic word errors were obtained from a variety of tasks, including single-picture naming, spelling to dictation, and the sentence-elicitation task that was the source of verb errors. For V. B. R., the source of monomorphemic errors included spoken picture-naming and elicitation tasks. The numbers of monomorphemic errors in each error pool were as follows—96 for A. E. S., 131 for D. H. Y., 144 for K. S. R., 309 for P. W., and 224 for V. B. R. To make mono and multimorphemic words more

Table 2. Participants' Accuracy on Verb and Noun Inflections for Spoken and Written Words

	Correct inflections		Comparison of spoken and written words		
Participant	Spoken words	Written words	χ^2	Effect size	95% confidence interval
D. H. Y.	92%	52%	$\chi^2(1, N = 128) = 25.6$*	39.9%	[26.0, 53.9]
K. S. R.	96%	80%	$\chi^2(1, N = 182) = 11.3$*	15.3%	[6.1, 24.6]
A. E. S.	100%	84%	$\chi^2(1, N = 177) = 27.4$*	16.4%	[10.6, 22.3]
P. W.	99%	41%	$\chi^2(1, N = 290) = 177.8$*	57.9%	[50.4, 65.4]
V. B. R.	42%	97%	$\chi^2(1, N = 570) = 281.9$*	–55.6%	[–50.4, –60.8]

*$p < .001$.

comparable, we used only multimorphemic targets that ended with consonant clusters attested in monomorphemic words (e.g., the cluster /st/ at the end of *passed* occurs in monomorphemic words *best* or *toast*, whereas the cluster /rkt/ at the end of *worked* never occurs in monomorphemic words).

For each participant, on each of the 10,000 runs of the analysis, each inflected word error was randomly paired with a monomorphemic word error produced in response to a target word of the same length. For example, D. H. Y.'s target-error pair *jumping* → *jump* was randomly paired with the monomorphemic error *calorie* → *calaria* on one run and with *vampire* → *vimpare* on another run. Error positions were normalized to permit comparisons across different word lengths. Normalization was based on the inflected words, with segments assigned to one of three bins—the first half of the stem, the second half of the stem, and the inflection. For example, for the writing error *jumping* → *jump*, the first bin (*ju*) and the second bin (*mp*) were both credited with two of two letters correct, whereas the third or inflection bin (*ing*) was credited with zero of three letters correct because of the omission of the inflection. Letter positions were similarly binned for the errors on monomorphemic words. For example, for the error *calaria*, the bin assignment of letter positions was comparable with that of *jumping* (*ca* in the first bin, two of two letters correct; *lo* in the second bin, one of two letters correct; *rie* in the third bin, two of three letters correct). This process provided a distribution of errors across letter position for monomorphemic errors against which the observed error distributions across letter position for the inflectional error responses could be compared.

The results are reported in Figure 2. Segment errors occurred across all positions for both word types, which indicated that errors were not limited to inflections. However, for the inflected words, stem-segment accuracy was markedly and statistically greater than inflection-segment accuracy (A. E. S.: 91% vs. 27%, respectively; P. W.: 82% vs. 14%, respectively; K. S. R.: 95% vs. 22%, respectively; D. H. Y.: 95% vs. 0%, respectively; and V. B. R.: 73% vs. 32%, respectively; χ^2 *p*s < .0001). More important for evaluating the word-final hypothesis was that all participants were less accurate with segments (letters or phonemes) in the inflection bin compared with segments occurring in the corresponding final positions of monomorphemic words (A. E. S.: 27% vs. 61%, respectively; D. H. Y.: 0% vs. 60%, respectively; P. W.: 14% vs. 34%, respectively; K. S. R.: 22% vs. 57%, respectively; V. B. R.: 32% vs. 81%, respectively). In the 10,000 runs of the Monte Carlo analysis, the accuracy observed in the final position for monomorphemic errors was always higher than the accuracy observed in the final position for multimorphemic errors (*p*s < .0001). In other words, for all participants, errors occurred significantly more frequently in final positions for multimorphemic versus monomorphemic words ($p < .0001$). In fact, the hypothesis that inflectional errors are nothing more than word final errors receives no support from this analysis.

Analysis 2: Lexical neighbor errors?

Although we do not have a complete understanding of the characteristics of word neighbors, it is generally agreed that neighbors share (a) a large proportion of letters or phonemes, especially the initial segment, and (b) a grammatical category (see Dell, Oppenheim, & Kittredge, 2008; Goldrick, Folk, & Rapp, 2010). Given that inflectional errors exhibit these same features, it is appropriate to investigate whether the inflectional errors we observed corresponded simply to neighbor errors. In other words, if participants mis-selected word neighbors during lexical selection, could it be that inflected forms were simply one of the many formal neighbors in the set? In that case, the probability of the inflectional error *tying* → *tied* should match the probability with which the inflectional neighbors occur in the neighborhoods of the target words. We evaluated this prediction using the data for verbs, because these were tested with all participants.

For this analysis, we first determined the set of neighbors of each target verb for which an apparent inflectional error had been produced. As illustrated in Table 3, for each word that had resulted in a lexical error (any real word error), neighbors were defined as all words that (a) were within plus or minus 10% of the target-error similarity (in terms of segment length and percentage of shared segments), (b) shared the same initial segment as the target, and (c) were verbs.[1] For each lexical error, neighbors of the target word with these characteristics were identified in the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993). Note that for this analysis, we included only errors in which the stem was produced correctly, because responses with stem errors, such as *walked* → *wolk*, could not occur in the neighbor set.

A Monte Carlo analysis was used to determine the chance rate of selecting an inflected form (*tying* → *ties*) from the neighbor set. On each of the 10,000 runs of the analysis conducted for each participant and for each target word (e.g., *tying*), a word from the neighbor set (see Table 3) was randomly selected as a candidate error. The proportion of inflectional errors (*tying* → *ties, tied*) selected by this random process was then tabulated.

The probability distribution of the expected inflectional errors was used for significance testing (see results for D. H. Y. in Fig. 3). The results (Table 4) reveal that the number of inflectional errors produced by the participants significantly exceeded the number of inflectional errors observed in the 10,000 runs of the Monte Carlo

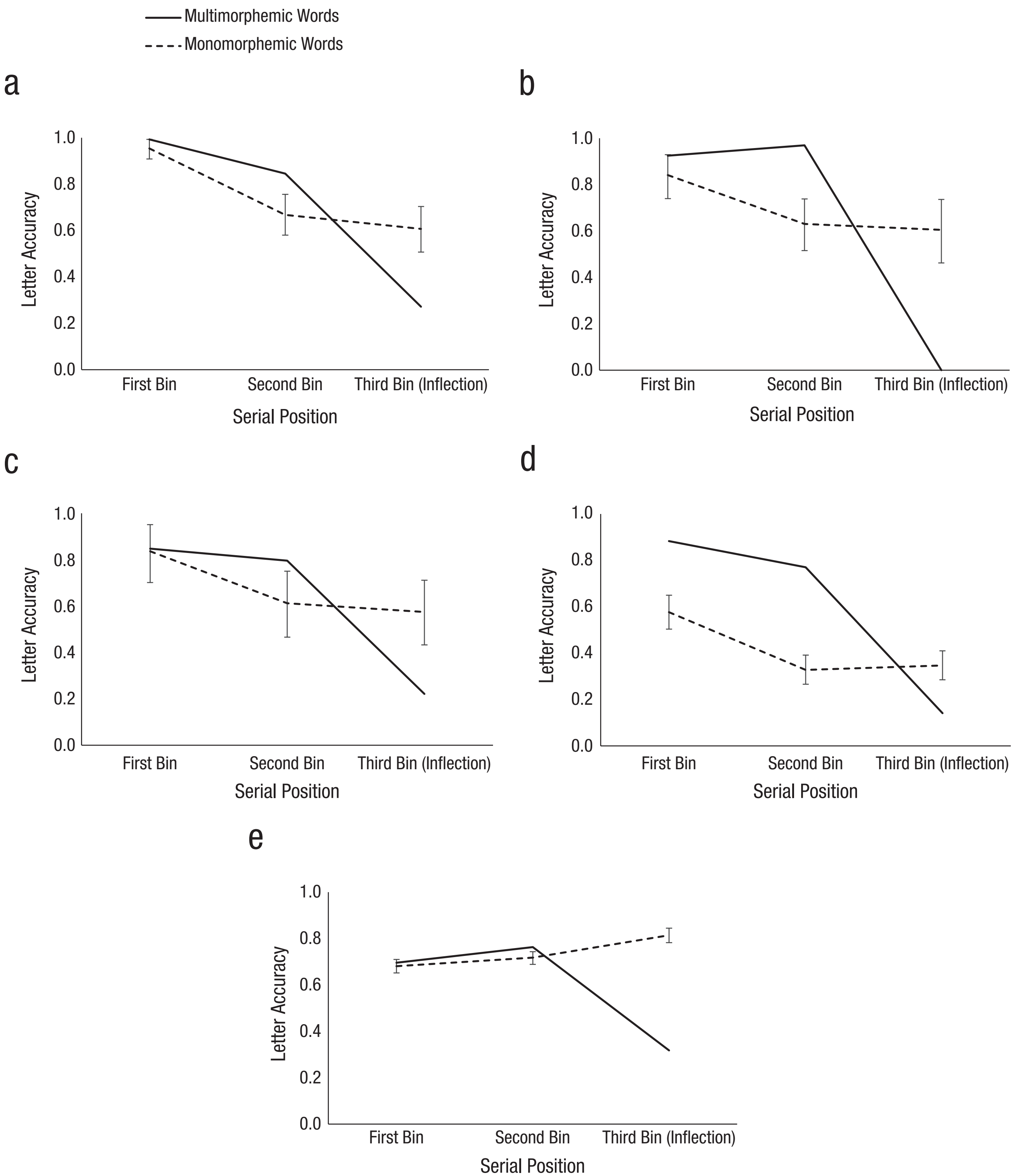

Fig. 2. Analysis for the word-final hypothesis. Letter accuracy is graphed as a function of position for multimorphemic and length-matched monomorphemic words. For multimorphemic words, segment accuracy was scored in three bins: the first half of the stem (first), the second half of the stem (second), and the inflection (third/inflection). Monomorphemic word bins corresponded to the same serial positions as in the matched multimorphemic items. Accuracy is based on written responses for (a) A. E. S., (b) D. H. Y., (c) K. S. R., and (d) P. W. and on spoken responses for (e) V. B. R. The error bars reflect bootstrapped 95% confidence intervals around the mean for the monomorphemic word accuracy distributions.

Table 3. Analysis 2: The Characteristics of the Lexical Neighbor Set for the Target Word-Error Pair *Tying* → *Tied*

Characteristic	Observed written error: *tied*	Matched candidate errors in CELEX (n = 69)[a]
Number of letters	4	4–6
Percentage of letters shared with target	44% (4 of 9)[b]	34%–54%
Part of speech	Verb	Verb
Initial letter	*t*	*t*
Number of morphological neighbors	—	2 (*ties, tied*)

[a]Matched candidate errors included *ties, tied, time, trying, tend*, and so forth. [b]*Tying* and *tied* have a total of nine letters, and four of the nine (*t* and *i* in *tying* and *t* and *i* in *tied*) appear in both words.

analysis that instantiated the hypothesis that the observed errors simply corresponded to the mis-selection of lexical neighbors. These findings clearly reveal that the observed inflection errors cannot be accounted for in terms of a concealed neighborhood effect.

General Discussion

The finding of modality-selective difficulties in producing inflected forms provides strong support for the morpho-orthography hypothesis, according to which inflectional processes operate not only at abstract levels and within the spoken language system but also within the orthographic system. Our findings represent a challenge for a contrasting architecture in which morphological operations are limited to the spoken modality because, in such a system, the orthography would lack the representations or processes needed to yield errors in which inflections (rather than random letter sequences) would be specifically deleted or substituted. The double dissociation (in which the production of inflections is more severely disrupted in writing than speaking, or vice versa) supports the independence of the modality-specific morphological operations. The fact that the observed deficits cannot be explained as difficulties with word endings or as resulting from the mis-selection of formal neighbors strengthens the claim that the affected operations are indeed morphological. As generally recognized, double dissociations reduce the likelihood that the observed dissociations result from irrelevant variables such as task difficulty or attentional demands. If morphological processing were more demanding in written production, we would not expect the complementary pattern of difficulty with inflections in spoken production.

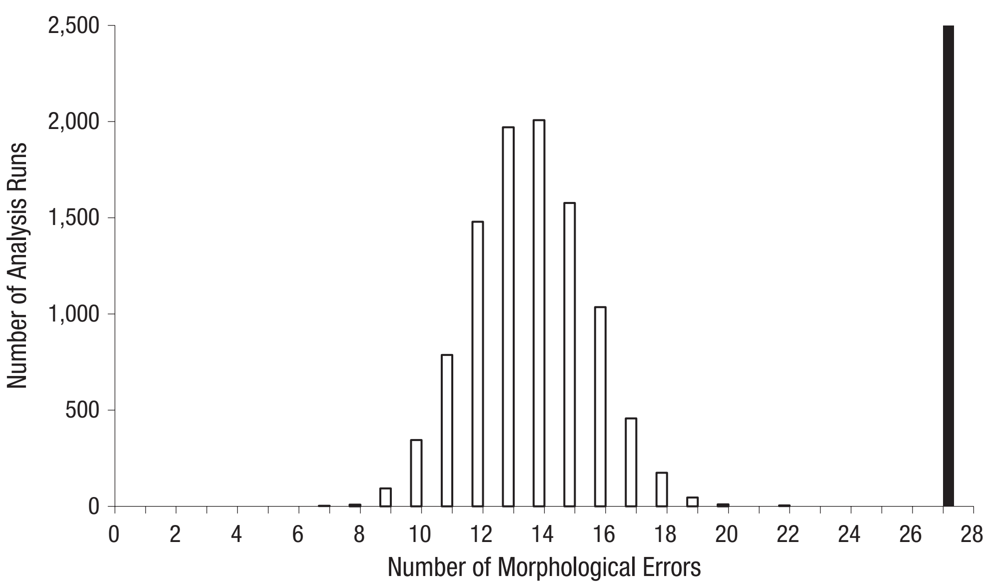

Fig. 3. Analysis of the lexical-neighbor hypothesis. The graph shows the distribution of the numbers of morphological errors expected by chance for D. H. Y.'s data set, as determined by 10,000 runs of a Monte Carlo analysis. The black bar on the right shows the number of errors actually made by D. H. Y. Similar distributions were obtained for the other participants, and findings are reported in Table 4.

Table 4. Rates of Morphological Errors Observed Compared With Those Expected Under the Lexical-Neighbor Hypothesis

			Lexical errors related morphologically to the target		
Participant	Modality	Number of lexical errors	Number observed	Mean number expected by chance	Observed versus expected
A. E. S.	Written	17	12 (71%)	3.8 (22%)	$p < .0001$
K. S. R.	Written	13	9 (69%)	3.0 (23%)	$p < .0001$
D. H. Y.	Written	29	27 (93%)	13.7 (47%)	$p < .0001$
P. W.	Written	58	44 (76%)	9.1 (16%)	$p < .0001$
V. B. R.	Spoken	306	225 (74%)	115.3 (38%)	$p < .0001$

The presented evidence is consistent with results from the small number of previous reports indicating sensitivity to morphological structure in the written production system. Badecker, Hillis, and Caramazza (1990) described individuals who had orthographic working memory deficits but (a) lower error rates for morphologically complex words than for monomorphemic words and (b) error distributions that respected stem and inflection boundaries. Berndt and Haendiges (2000) reported an individual who exhibited greater difficulties with verb inflections in writing than in speaking, whereas Badecker, Rapp, and Caramazza (1996) described a complementary difficulty in writing word stems but not affixes. Finally, with neurologically intact individuals, Kandel, Spinelli, Tremblay, Guerassimovitch, and Álvarez (2012) found that writing times for letters preceding morpheme boundaries were longer in suffixed words than in pseudo-suffixed words.

Chomsky and Halle (1968) famously remarked that "English orthography, despite its often cited inconsistencies, comes remarkably close to being an optimal orthographic system for English" (p. 49). They were referring to the fact that, among other things, morphological information is sometimes more consistently represented in the orthography than in the phonology. For example, the plural morpheme is consistently spelled with *s* in *cats* and *dogs* despite being realized with different phonemes (/s/ vs. /z/). Regardless of one's view of the optimality of English orthography, their position highlights the notion that the independence of orthographic representation extends to higher-level aspects of linguistic representation. Although the orthography is a representational system that clearly originated in the phonological system, the evidence we have reported reveals its capacity for the independent representation of linguistic information. This does not imply that the phonological and orthographic systems always function in isolation, because there is also evidence that both are active during production in either modality (Damian & Bowers, 2003; Damian et al., 2011). Likewise, one might wonder whether morpho-orthography occurs only in opaque orthographies with unpredictable phonology-orthography mappings. The neuropsychological report (Miceli, Mazzucchi, Menn, & Goodglass, 1983) of an Italian individual who produced morphological errors in spoken but not written sentence production suggests that orthographic depth may not be critical, although more research is warranted.

Presumably, the capacity for modality-specific orthographic processing at higher linguistic levels develops with increasing expertise and adds to the efficiency and speed of written word production. Understanding that the end state of the written production system involves orthographic representations and processes sensitive to the morphological structure of words is relevant for literacy instruction and rehabilitation. Considerable research has examined the relationship between general morphological skills and literacy development (Nagy, Beninger, & Abbott, 2006); the development of morpho-orthography has received less attention (but see Egan & Tainturier, 2011; Treiman & Cassar, 1996). Learning and rehabilitation experiences that target orthographic morphological structures and processes may contribute to developing the type and level of expertise of the adult writer.

In conclusion, one can only surmise that Gordinier, Wernicke, and colleagues would have responded with great interest to the evidence presented here revealing the brain's capacity to instantiate linguistically sophisticated features of written language with considerable neural independence from evolutionarily older skills such as spoken language.

Author Contributions

B. Rapp developed the experimental question and experimental design in collaboration with M. Miozzo. B. Rapp and S. Fischer-Baum designed and carried out the Monte Carlo analyses. The three authors contributed substantively to the data collection and the writing of the manuscript. All authors approved the final version of the manuscript for submission.

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Note

1. For example, for the error *tying* → *tied*, the word *type* would count in this set of errors because it (a) shares the same initial letter, (b) is a verb, (c) is the same length (four letters) as the error, and (d) has the same number of letters overlapping with the target (two) as the actual error. The word *tame* would not be included, because the number of overlapping letters is less than that in the actual target-error pair. The word *tenure* would not be included: even though it has the same number of letters overlapping with the target (two) as the actual error, it is longer than the error (four vs. six letters).

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