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A selective morpho-phonological deficit?

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ABSTRACT
We report on an English-speaking, aphasic individual (TB) who showed a striking dissociation in speaking with the different forms (allomorphs) that an inflection can take. Although very accurate in producing the consonantal inflections (-/s/, -/z/, -/d/, -/t/), TB consistently omitted syllabic inflections (-/əz/, -/əd/), therefore correctly saying “dogs” or “walked,” but “bench” for benches or “skate” for skated. Results from control tests ruled out that TB’s selective difficulties stemmed from problems in selecting the correct inflection for the syntactic context or problems related to phonological or articulatory mechanisms. TB’s selective difficulties appeared instead to concern morpho-phonological mechanisms responsible for adapting morphological elements to word phonology. These mechanisms determine whether the plural inflection surfaces in the noun bench as voiced (-/z/), unvoiced (-/s/) or syllabic (-/əz/). Our results have implications for understanding how morphological elements are encoded in the lexicon and the nature of morpho-phonological mechanisms involved in speech production.

Languages extensively exploit the possibility of creating words by combining smaller elements, which are generally referred to as morphemes. Thus, the concatenation of the morphemes use, less, and ness gives rise to the word uselessness. Understanding how morphemes are represented and retrieved is a primary goal for accounts concerning the brain mechanisms of word production. Morpheme selection for production implies a tight interaction with semantic and syntactic processes, since morphemes have to satisfy precise semantic and syntactic constraints. Linguists have also recorded many examples across languages of morphemes that vary predictably depending on the phonological environment. An example is found in English with the morpheme marking the plural of nouns that alternates between /z/ and /s/ depending on a phonological feature (voicing) of the preceding phoneme – /z/ with a voiced preceding phoneme (dogs, /dɒgz/), /s/ with an unvoiced preceding phoneme (cats, /kæts/). This type of morpheme makes a strong case for a tight interaction between morpheme selection and word sound processing. Linguistic descriptions have typically associated these morpheme variations with phonological constraints and language-specific preferences (e.g., Berent, 2013; Bybee, 2010; Carstairs-McCarthy, 2005; Chomsky & Halle, 1968; Dressler, 1985; Embick, 2010; Kiparsky, 2000), and in some cases proposed that these morphological variations represent suitable adaptations to phonology (Gussenhoven & Jacobs, 2013; Gussmann, 2002; Haspelmath, 2002; McCarthy & Prince, 1999). In this regard, the voice agreement observed with English plural nouns appears to conform to a general preference for having adjacent phonemes with identical voice features (Gafos, 2014; Hayes, Kirchner, & Steriade, 2004). The question that these morphological variations raise for neurocognitive accounts concerns the nature of the processes underlying the interaction between morphology and phonology. We address it from the perspective of speech production.

There are multiple ways in which the interaction between morphology and phonology could shape processing. A primary question relates to the degree of specification of individual morphological variants (allomorphs). Two general hypotheses can be proposed to address this question. Under one hypothesis, lexical representations fully specify the allomorphs words take. For example, the lexical representation of dog and cat would specify that their plural require a voiced and an unvoiced allomorph, respectively. We refer to this hypothesis as the full specification
hypothesis. Under the other hypothesis, lexical entries provide only partial information about the morphemes, lacking stored information that can, instead, be reliably obtained from the phonological environment. This hypothesis assumes that the lexical entries of English nouns encode whether the plural morpheme corresponds to an alveolar fricative without specifying whether it is voiced (/z/) or unvoiced (/s/). Additional processes determine whether, in that specific phonological context, the allomorph is voiced or unvoiced. These processes apply only to segments corresponding to morphemes and, therefore, are morpho-phonological in nature. We refer to this hypothesis as the partial specification hypothesis. A core assumption of this hypothesis is that specific phonological processes are required with some allomorphs, which, in turn, makes the processing of some individual allomorphs distinct. Furthermore, the hypothesis is based on the idea, mainstream in linguistics, that the surface form is derived from an underlying representation (Hall, 2014; Haspelmath, 2002).

Both hypotheses are endorsed by specific psycholinguistic accounts. The way in which the full specification hypothesis is implemented in part depends on whether or not theories assume that stems and affixes are distinctly represented and that the stem +affix composition takes place in word production. Under compositional accounts, affixes can be represented according to the hypothesis of either full or partial specification. Within compositional accounts that assume full specification, each type of allomorph is distinctively represented, and the production of morphologically complex forms entails the selection of the appropriate allomorph (e.g., -/z/) that is then combined with the stem (e.g., dog). An account of this kind was proposed by Levelt, Roelofs, and Meyer (1999). Alternatively, as assumed in the compositional models of Lapointe and Dell (1989), and Stemberger (1991), the affixes that are combined to stems are stored in an underspecified format, and it is only after stem+affix composition that additional phonetic features of the affix can be made explicit. On the other hand, non-compositional accounts, which assume that morphologically complex words are represented as whole words, are committed to a full specification hypothesis. In fact, because both stems and affixes are, by hypothesis, not “visible” to morphological processes, no information should be available for adjusting the affixes to the phonological context of the stems. Whether non-compositional representations hold for all multi-morphemic words familiar to a speaker (Taft, 1979), or only for relatively frequent words (Caramazza, Romani, & Laudanna, 1988; Hay & Baayen, 2005; Schreuder & Baayen, 1995), these non-compositional accounts must assume that the full specification of allomorphs holds at least for some of the words. As evident from the multiplicity of accounts, allomorph representation is an issue far from settled in psycholinguistics.

Language deficits provide an opportunity to discriminate between the hypotheses of full versus partial specification. Although both hypotheses can account for the finding that certain allomorphs are more impaired than others, their explanations differ in crucial ways. Under the partial specification hypothesis, processes adjusting morphemes to phonological contexts vary across allomorphs, allowing individual allomorphs to be differentially susceptible to damage. In contrast, because individual allomorphs are not distinctively processed under the full specification hypothesis, an allomorph-specific deficit can only be explained in terms of more general mechanisms that happen to affect the processing of that allomorph. For example, deficits specifically affecting the retrieval of low-frequency lexical features could specifically impact the least frequent allomorphs. The alternative hypotheses were tested by comparing the production of the allomorphs of plural nouns (-/z/, -/s/, -/az/) and the allophones of past tense verbs (-/d/, -/t/, -/ad/) in TB, an English speaker with impaired language production subsequent to acquired brain lesions. Only the partial specification hypothesis predicts that TB would be more impaired in producing one type of noun or verb allomorph than another because the specific mechanisms needed to process the allomorph are damaged.

The present investigation arose from the observation that TB produced the plural allomorphs -/z/ and -/s/ but omitted the syllabic allomorph -/az/. Thus, TB correctly said “dogs” or “cats”, but said “bench” instead of benches. Systematic testing of plural nouns confirmed the selective omission of syllabic allomorphs, a finding we replicated with the allomorphs marking verb past tense where, again, TB’s omissions were mainly confined to the syllabic allomorph -/ad/. These results appeared to be consistent with the partial specification hypothesis. Following
standard linguistic accounts (Dressler, 1985; Gussmann, 2002; Hapslmuth, 2002), TB’s omissions of syllabic allomorphs could be explained in terms of a deficit affecting the morpho-phonological processes responsible for vowel insertion that assure that the allomorph will surface in the expected form. As explained in detail below, we also examined alternative accounts of TB’s selective omissions of syllabic allomorphs, including accounts consistent with the full specification hypothesis. For example, syllabic allomorphs result in an additional syllable; we therefore considered whether TB’s omissions were traceable to problems in producing longer words that would especially affect syllabic allomorphs. Our results did not support the alternative accounts we examined. TB’s selective omissions were best explained by the partial specification hypothesis and in terms of a deficit affecting specific morpho-phonological processes.

Case description
TB is a male native English speaker who completed high school and worked in construction. At the age of 21, TB suffered a traumatic head injury causing extensive brain damage, in addition to bilateral, partial visual field loss, and cochlea damage in the left ear. TB’s injury resulted in a chronic language deficit. Testing took place 16 years after the injury, when TB was 37 years old. A computed tomography (CT) scan taken around the time of the present study revealed damage in bilateral frontal lobes, left temporal parietal regions, and right temporal regions. The CT scan also showed cortical volume loss and dilation of the left lateral ventricle. At time of testing, TB had a left cochlear implant. As suggested by the frequent requests he made to speakers to repeat or clarify, speech comprehension seemed compromised, possibly, in part, because of the hearing deficit caused by the injury. TB’s speech was hesitant, ungrammatical, and morphologically impoverished, with occasional articulatory difficulties. TB’s language was extensively assessed in part to identify the linguistic tasks TB was able to perform.

Speech recognition
Tests revealed that TB’s recognition of phonemes, spoken words, and sentences was compromised. Phoneme recognition was tested using a same/different discrimination task with CVC word pairs (PALPA 2; Kay, Lesser, & Coltheart, 1992). Words in different pairs varied by one phoneme (e.g., bed-bet). TB correctly identified 32/36 same pairs (z = −4.54) and 30/36 different pairs (z = −1.87). Spoken word recognition was tested using a sentence–picture matching task (PALPA 55; Kay et al., 1992) in which foils showed a different verb or a different noun as grammatical object (target: a girl is washing a dog; foils: a girl is petting a dog; a girl is washing a horse). TB responded correctly on 10/16 trials (z = −7.01). TB’s errors reflected confusions either between nouns (dog → horse) or verbs (washing → petting). To test spoken sentence comprehension, TB was again given a sentence–picture matching task. Foils in this task, however, showed the subject and object reversed (target: a dog is approaching a girl; foil: a girl is approaching a dog). TB responded correctly on 10/20 trials (z = −10.95).

Spoken word production
We selected 125 black and white pictures of objects for which at least 95% of the normal controls in Snodgrass and Vanderwart (1980) produced a name we scored as correct. TB was successful in naming only 95/125 pictures (76%; in all naming tasks, the final complete response was used for scoring). Object and action naming was similarly impaired, as indicated by TB’s similar z-scores with objects (z = −16.22; 45/60, 75%) and actions (z = −17.30; 14/30, 47%) matched for frequency and syllable length (Berndt, Mitchum, Haendiges, & Sandson, 1997). The incorrect responses TB produced across all of the naming tasks consisted of “don’t know” responses (21/61, 34%), semantic errors (sharpening → “erasining;” 22/61, 36%), and phonological errors sharing more than 50% of the phonemes in the target word (e.g., ripping → /rɪfɪŋ/; raft → /ræf/; 18/61, 30%).

Spoken word repetition
TB correctly repeated 31/76 (41%) of the monomorphic and monosyllabic words presented to him. TB’s poor repetition was likely the result of the combination of speech recognition and speech production deficits we documented above.

Reading aloud
Items from the Johns Hopkins Dyslexia Battery (Goodman & Caramazza, 1986) were administered to
TB in order to test reading aloud of words and non-words. Results demonstrated that TB was impaired with word reading, although he was more impaired when attempting irregular (e.g., *heir*) than regular (e.g., *boot*) spelling-sound mappings (13/36, 36% vs. 22/36, 61%; \( \chi^2(1) = 4.05, p < 0.05 \)). For 10/23 (43%) incorrectly read irregular words TB used a regular mapping, as in *plaid* → /pleid/ or *once* → /ənəs/. A length effect was observed as TB was more accurate with 4-letter words than 5-letter words matched for frequency (30/53, 57% vs. 9/32, 28%, \( \chi^2(1) = 6.52, p < 0.05 \)). A word frequency effect was also found: TB was more correct with high versus low-frequency words (18/29, 62% vs. 29/72, 40%, \( \chi^2(1) = 3.95, p < 0.05 \)). Many of the errors consisted of words similar both visually and phonologically (e.g., *dock* → “dᴧk;” *heir* → “hᴧr;” *dome* → “dᴧm”), or with slight changes to the word (e.g., *feather* → “fᴧʃər;” *elbow* → “eɭ ɬər”). TB correctly read 8/15 (53%) nonwords. All of the errors consisted of incorrect nonwords (e.g., *chenc* → /ʃeŋəb/). These results indicated that, although his nonword reading was clearly impaired, there was some residual ability to derive sounds from print.

### Experimental investigation

#### Production of inflected nouns and verbs

TB’s production of plural nouns was tested with picture naming. TB was presented with multiple pictures of an object (range 2–6) and was instructed to name the objects and their number (“two drums”). Only pictures that TB named successfully when presented individually in a pretest were selected for this task. The plural nouns of these pictures were of three kinds, taking one of the three different plural allomorphs: -/s/ (e.g., *lamps*; \( N = 29 \)), -/z/ (e.g., *chairs*; \( N = 57 \)), and -/z/ (e.g., *benches*; \( N = 30 \)). The plural nouns in the three lists were matched for surface and lemma frequencies, as well as for stem phoneme length (see Table 1 for descriptive statistics). Pictures were also presented as singletons in the same task, to which TB responded by producing the singular form of the object name and its number (“one drum”). Single pictures served as controls to assess whether there were more difficulties in identifying the objects and producing the stem morphemes in the case of plural nouns. Although each block contained a mix of singular and plural pictures, the singular and plural forms of a particular object were tested in separate sessions. The singular was tested once and the plural twice for each word.

There was no difference in stem accuracy when TB was presented with plural (221/232) and singular (110/116) nouns (95% vs. 95%; \( \chi^2(1) < 1 \)). Of the 17 errors involving stems, 10 were phonological, four were semantic (stool → “chair”), two were mixed (snakes → “snails”; shells → “scales”), and one “don’t know” response. The phonological errors involved individual phonemes, either their substitution (crutch → /krəʃ/) or omission (basket → /bækət/). In the next analysis, we focused on whether TB produced the plural allomorph correctly, ignoring minor segment errors in the stems as long as they did not compromise response scoring. Three responses were excluded from the inflection analysis because TB produced an incorrect stem that took a different allomorph than the target word (e.g., “holes” instead of *hoses*). Although highly accurate with -/s/ allomorphs (54/56, 96%) and -/z/ allomorphs (111/114, 97%), TB was correct with only 3/59 (5%) of the -/z/ allomorphs (\( \chi^2(1) = 189.60, p < 0.001 \); -/s/ and -/z/ allomorphs combined). Every error with syllabic allomorphs was due to -/z/ omission (e.g., *boxes* → “box”). Omissions also accounted for the few errors involving -/s/ and -/z/ allomorphs.

Table 1. Stem length (number of phonemes) and surface and lemma frequencies for words named by TB.

<table>
<thead>
<tr>
<th>Word/Allomorph</th>
<th>Length Mean (SD)</th>
<th>Surface Frequency Mean (SD)</th>
<th>Lemma Frequency Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-/s/</td>
<td>4.3 (1.0)</td>
<td>17.6 (30.4)</td>
<td>46.3 (77.6)</td>
</tr>
<tr>
<td>-/z/</td>
<td>4.2 (0.9)</td>
<td>19.8 (29.2)</td>
<td>68.2 (91.8)</td>
</tr>
<tr>
<td>-/az/</td>
<td>4.7 (0.8)</td>
<td>16.9 (25.1)</td>
<td>80.4 (133.0)</td>
</tr>
<tr>
<td>Verbs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-/s/</td>
<td>4.2 (0.7)</td>
<td>5.3 (7.5)</td>
<td>71.9 (103.9)</td>
</tr>
<tr>
<td>-/d/</td>
<td>4.3 (0.9)</td>
<td>8.5 (19.3)</td>
<td>92.1 (174.6)</td>
</tr>
<tr>
<td>-/sd/</td>
<td>4.7 (0.9)</td>
<td>4.7 (5.4)</td>
<td>46.5 (57.5)</td>
</tr>
</tbody>
</table>

Note: Frequencies obtained from CELEX database (Baayen et al., 1993).
tense verbs were matched for lemma and surface frequencies, and stem phoneme length (see Table 1 for descriptive statistics). Each verb was tested between one and three times over multiple sessions, for a total of 25 -/d/ verbs, 50-/t/ verbs, and 26-/ad/ verbs.

Inflected verbs were scored according to the procedure described above with inflected nouns. The 13 errors TB made with verb stems resulted from phonological errors (N = 10) and semantic errors (N = 3). Five responses from the-/ad/ trials were excluded from the inflection analysis because the incorrect stem produced by TB took a different allomorph than the target word (e.g., -/d/ instead-/ad/ when TB responded /ɪˈrɔːbd/ for erupted). TB was much less successful with the-/ad/ allomorph (1/21; 5%) than the other allomorphs (-/d/: 20/25, 80%; -/t/: 47/50, 94%; χ²(1) = 56.79, p < 0.001, -/d/ and -/t/ allomorphs combined). The errors TB produced for-/ad/ allomorphs consisted of substitutions of the present active inflection -ing, as in painted → “painting” (N = 10) and the derived suffix -er (N = 2, e.g., toasted → “toaster”), or inflection omissions, as in voted → “vote” (N = 8/20). The same types of errors were observed when TB attempted the allomorphs-/d/ and-/t/ (seven affix substitutions with -ing, and one omission).

The severe difficulties TB experienced in noun and verb naming with syllabic allomorphs stood in stark contrast with his high accuracy with consonantal allomorphs. These discrepancies can be explained under the partial specification hypothesis by assuming a deficit affecting the specific mechanism underlying syllabic allomorphs. However, there are alternative explanations that must be evaluated concerning the relative intactness of performance with consonantal allomorphs and the selectivity of the impairment with syllabic allomorphs. Assessing these alternative explanations is also relevant for evaluating the full specification account.

A lexical deficit?

We extensively investigated whether the differences with which TB produced the allomorphs reflected the frequencies in the language of the words carrying the allomorphs or the allomorphs themselves. Examining frequency effects is especially necessary if we consider that TB’s lexical access was impaired as evidenced, for example, by his recurrent wordfinding difficulties (see Case Description). Because low-frequency items are typically more severely affected by lexical-access deficits, it is essential we assess whether TB’s problems with allomorphs derived from specific difficulties in accessing low-frequency items.

As mentioned above, the words carrying syllabic and consonantal allomorphs were matched for word frequency, operationalized as the occurrences of the inflected words in the CELEX corpus (Baayen, Piepenbrock, & Van Rijn, 1993). This rules out that TB was especially impaired with-/az/ and-/ad/ because these syllabic allomorphs occurred in relatively low-frequency words.

Nevertheless, the frequencies of the syllabic allomorphs themselves could have been responsible for TB’s selective difficulties with these allomorphs. The accuracy with which impaired features are produced often depends on their frequencies, as demonstrated, for example, with deficits affecting syllables (e.g., Lagardo, 2008) or inflections (e.g., Cholin, Rapp, & Miozzo, 2010; Luzzatti, Mondini, & Semenza, 2001). Similar frequency effects could be at play with TB’s allomorph deficit. To investigate this possibility, we first obtained counts of allomorph occurrences in the CELEX database (Baayen et al., 1993). For each of the allomorphs tested with TB, we determined its type frequency (the total number of words bearing the allomorph) and its token frequency based on the occurrences of each word carrying the allomorph. While type frequency reflects the range of words in which the allomorph appears, token frequency relates more directly to the probability of encountering the allomorph. Of relevance here is the comparison of syllabic and consonantal allomorphs. As shown in the summary presented in Table 2, syllabic allomorphs have the lowest type frequency counts among plural nouns.

<table>
<thead>
<tr>
<th>Type Frequency</th>
<th>Token Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Noun Allomorphs</strong></td>
<td></td>
</tr>
<tr>
<td>-/s/</td>
<td>3409</td>
</tr>
<tr>
<td>-/t/</td>
<td>101741</td>
</tr>
<tr>
<td>-/z/</td>
<td>1364</td>
</tr>
<tr>
<td><strong>Verb Allomorphs</strong></td>
<td></td>
</tr>
<tr>
<td>-/t/</td>
<td>1089</td>
</tr>
<tr>
<td>-/d/</td>
<td>2869</td>
</tr>
<tr>
<td>-/ad/</td>
<td>1611</td>
</tr>
<tr>
<td><strong>Adjective Inflection</strong></td>
<td></td>
</tr>
<tr>
<td>-er</td>
<td>870</td>
</tr>
</tbody>
</table>

Note: Frequencies obtained from CELEX database (Baayen et al., 1993).
but not among past tense verbs (the least represented allomorph is -/t\^/). One-way ANOVAs carried out to compare the (log-transformed) frequency counts of words bearing each of the plural noun allomorphs (-/s/, -/z/, -/\oz/), or each of the verb past tense allomorphs (-/t/, -/d/, -/\ad/), revealed significant ($p < 0.05$) differences in the distributions of both kinds of allomorphs. As indicated by Tukey's post-hoc tests, these differences were accounted for by greater token frequencies for -/s/ than -/z/ ($p = 0.01$), and for -/t/ than -/\ad/ ($p < 0.05$), respectively. Even in terms of token frequencies, therefore, syllabic allomorphs are not the least common, as their token frequencies were comparable with those of the consonantal allomorphs -/s/, -/z/, or -/d/. In short, the distributions of neither type nor token frequencies fit well with TB's selective deficits with syllabic allomorphs. For example, TB was rather accurate with -/t/, whose type frequency was lower than -/\ad/, and with -/s/ and -/z/ and -/d/ that have comparable token frequencies with -/\oz/ or -/\ad/, respectively.

A more direct test of allomorph frequency was conducted using the inflection -er that marks the comparative form of some English adjectives (colder, smaller). This inflection is less common compared with the syllabic allomorphs -/\oz/ and -/\ad/, in terms of both type frequency (870 occurrences) and token frequency (-er vs. -/\oz/, $t(2117) = -7.038, p < 0.0001$; -er vs. -/\ad/, $t(2479) = 1.698, p = 0.09$). If TB's responses were modulated by affix frequency, we would expect TB to be especially impaired with the adjectival affix -er. This prediction was tested using a naming task specifically designed to elicit adjectives and their -er comparatives. The experimenter first introduced the adjectives by naming the adjective corresponding to each picture (e.g., colder for a picture showing a person wearing a heavy coat). Next, TB was shown two pictures side-by-side that depicted the same adjective (e.g., cold), though one did it more emphatically and, thus, was expected to elicit the comparative form of the adjective (colder). TB was instructed to name the adjective in its comparative form ("colder"). The comparative adjectives we tested (N = 13) had one-syllable stems and were matched in length and surface frequency with the -/\oz/ plural nouns used in the earlier picture-naming task (mean = 24.4; t with $p = 0.5$). Three responses were elicited for each adjective. TB produced 38/39 of the -er inflections correctly (the single error was paler $\rightarrow$ “per”).

Results with the adjectival inflection -er provide additional evidence that TB's deficit with syllabic allomorphs is not related to allomorph frequency. It is important to mention that although -er is also a syllabic morpheme, it is not assumed to involve morphophonological processes. In this respect, -er differs from the syllabic allomorphs that TB failed to produce. This crucial difference explains why TB was able to correctly produce the syllabic morpheme -er but not the syllabic allomorphs.

A phonological deficit?
To what extent are consonantal allomorphs spared? The consonants that in English mark noun plural or verb past tense give rise to consonant clusters of different complexity. Prior results showed that producing the more complex consonant clusters could be especially difficult in conditions of phonological/articulatory deficits (Bird, Lambon Ralph, Seidenberg, McClelland, & Patterson, 2003; Miozzo & Buchwald, 2013). This might be true for TB as well. To the extent that TB's phonological errors in naming suggest the presence of phonological/articulatory deficits, TB could also have been sensitive to the complexity of consonant clusters. In light of TB's phonological/articulatory deficit, we systematically analyzed TB's production of consonantal allomorphs to establish whether or not TB correctly produced even those allomorphs that resulted in complex clusters.

The affixation of consonantal allomorphs often results in segment sequences that are complex on two grounds. First, sequences may comprise multiple consonants, as is the case with cups and lamp\_s. The second source of complexity relates to the low sonority of the obstruct consonants corresponding to the consonantal allomorphs (/s/, /z/, /t/, and /d/). Obstruent consonants are dispreferred in syllable coda positions (the positions in which they occur in affixation), as demonstrated by linguistic evidence (e.g., cross-linguistic frequencies; Clements, 1990; Greenberg, 1978) or the late acquisition of these segments in language development (McLeod, van Doorn, & Reed, 2001). Especially dispreferred and complex in coda positions are obstruct-obluerent sequences that, nevertheless, are common among English inflections, as attested by examples like dots [d\_\_ts] and missed [m\_\_st]. Crucially, individuals with language impairments affecting phonological/articulatory
processes find these complex segment sequences especially difficult to produce (Bird et al., 2003; Goldrick & Rapp, 2007; Miozzo & Buchwald, 2013; Romani & Calabrese, 1998; Ziegler, 2005). Of potential concern is whether TB produced consonantal allomorphs in simple but not in complex phonological environments. A post-hoc analysis of TB’s responses with plural nouns and past tense verbs ruled that out. Indeed, TB was comparably accurate when inflections occurred in codas formed by two versus three consonants (e.g., cups vs. lamps; 208/220, 95% vs. 32/34, 94%; $\chi^2(1) < 1$). Furthermore, TB was similarly accurate when inflections formed obstruent-obstruent clusters relative to the less complex sonorant-obstruent clusters (e.g., cups vs. dolls; 76/79, 96% vs. 89/92, 97%; $\chi^2(1) < 1$).

**Segment and syllable length**

The syllabic allomorphs problematic for TB differ from the consonantal allomorphs by the addition of two segments and a whole syllable. Language deficits sometimes make longer words more difficult to produce (Croft, Patterson, & Hodges, 1998; Kittredge, Dell, Verkuilen, & Schwartz, 2008; Nickels & Howard, 1995, 2004; Pate, Saffran, & Martin, 1987; Ziegler, 2005), a type of problem that TB could have also experienced, which could be responsible for his selective problem with syllabic allomorphs. TB’s correct responses with the comparative adjectives carrying the syllabic inflection -er (presented above) cast doubt on an explanation of TB’s difficulties in terms of the greater segment length of the syllabically affixed words. The present active suffix -ing, which involves an identical length increase, provides a further opportunity to test the length account. According to this explanation, TB’s impairment would extend to the -ing suffix. This prediction was tested by showing TB the same pictures as for the past tense verb picture-naming task with the prompt “What is he doing?” Each verb was tested one to five times over multiple sessions ($N = 165$). TB correctly produced the suffix -ing for 157/165 (95%) of verbs. His errors consisted of substitutions (e.g., jumping → “jumped”; $N = 3$) and omissions (squeezing → “squeeze”; $N = 5$). The relatively high accuracy with which TB produced -ing suffixes lends no support to an explanation based on word and syllable length. It is interesting to note that the errors in which TB substituted -/d/ with -ing also suggest that it is not an issue of length or syllable addition.

**Phoneme similarity**

The syllabic insertion resulting in syllabic allomorphs occurs specifically to separate consonants that are either similar (the two sibilants in *bench*es) or repeated (the /d/ in *fold*ed). Analyses of articulation times conducted on unimpaired speech revealed longer times for words containing similar consonants, for example, the voiceless stops /k/ and /t/ in *cat* (Bailey & Hahn, 2005; Cohen-Goldberg, 2012, 2013). Because the longer articulation times suggest that similar consonants undergo more complex processing, this complexity could make the processing especially vulnerable in pathological conditions. Critically, if, in these contexts, TB can only produce one of the similar or repeated consonants, we would expect to find the types of omission errors that TB produced with syllabic allomorphs. It should be noted that weaker effects of consonant similarity were reported for consonants occurring in different morphemes (Cohen-Goldberg, 2013), corresponding to the inflected word condition we examined. To examine how TB produced similar and repeated consonants, we analysed all the CVC monomorphemic words named by TB throughout the course of this study that contained either repeated or similar consonants (e.g., *cake; judge*). The similar (non-repeated) consonants of these words received the highest similarity score based on place and manner of articulation, voicing, and sonority (Bailey & Hahn, 2005). As TB correctly produced repeated and similar consonants in 45/45 of these words, there was no indication that TB’s difficulties with syllabic allomorphs were related to consonant similarity or repetition.

**An impairment with articulatory processes?**

Detailed investigations have revealed a wide variety of phonological and articulatory processes that may be impaired with different degrees of selectivity in language deficits subsequent to acquired brain damage (Buchwald & Miozzo, 2011; Galluzzi, Bureca, Guariglia, & Romani, 2015; Goldrick & Rapp, 2007; Haley, Jacks, & Cunningham, 2013; Laganaro, 2012; Ziegler, 2005). Such a variety is likely to reflect the complexity of phonological and articulatory deficits
that presently is little understood, to the point where we cannot always rule out a priori whether a specific feature could be more or less affected by phonological and articulatory deficits. In several cases, this can be established only empirically. As a step in this direction, we tested TB’s production of noun plurals in reading, as we reasoned that this task would provide an opportunity to uncouple morphological and phonological/articulatory processes. As reported in the Case Description section, TB’s reading was impaired especially when attempting words with unpredictable print-sound mapping, which he would often read according to probable correspondences. The nature of these errors suggests a reliance on non-lexical print-sound transcoding procedures that were at least partially available to TB, as further indicated by some ability to read nonwords. There was also evidence that print-sound transcoding procedures supported TB’s reading of inflected words, as shown, for example, by errors like baked [beikt] → /beikad/ in which the sounds of the written inflection -ed were derived sublexically. If segments that are weakly activated in naming receive additional activation through the non-lexical route, there is a chance that TB could produce them in reading. Specifically, in reading, TB could associate the letter -e to the phoneme /ə/, and therefore would correctly read the word *dishes*, even though he was unable to name “dishes”. However, if TB’s difficulties with syllabic allomorphs were related to phonological or articulatory deficits that do not interface with morphology, such difficulties would persist in reading.

The names of the 116 pictures of multiple objects that we used in the naming task were re-presented for reading aloud. Object names and numbers were written above the pictures (e.g., *Two drums*). Pictures were included to provide some cues about the written word and its number. TB read each plural noun twice, over multiple sessions. As in the naming tasks, TB’s final complete response was scored. We focused on whether TB read the plural allomorph correctly, ignoring minor segment errors in the stems as long as they did not compromise response scoring. TB correctly read 167/172 (97%) of the consonantal allomorphs, and 56/60 (93%) of the syllabic allomorphs. The results with syllabic allomorphs were therefore markedly different in reading than naming: Not only in reading were syllabic allomorphs produced as accurately as consonantal allomorphs ($\chi^2(1) = 1.7, p = 0.19$), but they were also produced with extremely higher accuracy than in naming (93%; vs. 5%, $\chi^2(1) = 92.68, p < 0.001$). TB’s errors with the allomorphs consisted of three substitutions (e.g., *skirts* → “skirtes”) and six omissions (pears → “pear”).

In sum, the finding that the production of syllabic allomorphs is spared in reading is strong evidence that TB’s difficulties with these allomorphs did not stem from phonological or articulatory processes that do not interface with morphology.

**General discussion**

TB, whose brain damage resulted in hesitant and ungrammatical speech punctuated by errors, showed a clear-cut dissociation between syllabic and consonantal inflections for both plural nouns and past tense verbs. Although able to produce the consonantal allomorphs -/z/, -/s/, -/d/, and -/t/, TB virtually always omitted the syllabic allomorphs -/az/ and -/ad/. The specificity of TB’s omissions makes it clear that TB’s problem is not so much one of selecting the morpheme required by the semantic and grammatical context; rather, it is one of selecting the appropriate morpheme form (i.e., the allomorph). Strikingly, the omissions of syllabic allomorphs, so pervasive in naming, were mostly absent in reading aloud. This task specificity rules out explanations relating TB’s omissions to phonological and articulatory processes that do not intersect with morphology. The pattern of results that emerged from TB points instead to a deficit involving morpho-phonological features. In addition, we can rule out length (syllabic and phonemic) and consonant similarity as features making syllabic allomorphs difficult. In fact, even in naming, TB accurately produced the inflections -ing and -er that match the length of the problematic syllabic allomorphs -/az/ and -/ad/ and CVC words whose consonants were either identical (e.g., *cake*) or similar (e.g., *cat*). Finally, various lines of evidence make it unlikely that the frequencies of syllabic allomorphs contributed to TB’s difficulties with these features.

It seems difficult to explain TB’s selective deficit under the hypothesis we referred to as full specification, which assumes identical forms of representation and processing for all types of allomorphs. As mentioned in the introduction, this hypothesis can be instantiated in different ways. Under one version, inflected words are represented as whole words, in an un-decomposed form. A hypothesis of this kind
would primarily predict non-selective deficits affecting all types of allomorphs, as well as effects of surface frequency (i.e., the specific frequency of the inflected word). TB’s data were consistent with neither of these predictions. According to another version of the full specification account, inflected words are assembled by their component parts. Under an account of this kind, deficits could affect a single type of morpheme. However, the co-occurrence in TB of deficits for the allomorphs /az/ and /ad/ would be simply considered as coincidental. A more detailed explanation relating to allomorph frequency is provided within the framework of theories assuming morphological composition: the vulnerability of syllabic allomorphs could reflect their relatively low frequency. However, results from our extensive investigation of allomorph frequency do not support this type of account. TB’s deficit is instead more consistent with the partial specification hypothesis that proposes distinct forms of processing for the different types of allomorphs. By assuming that the processes responsible for adjusting the morphemes to specific phonological environments vary across allomorphs, the partial specification hypothesis can account for deficits restricted to certain types of allomorphs, in particular, those that require schwa insertion. The hypothesis, however, is poorly detailed in many respects, a limitation that makes it impossible to predict whether one allomorph versus another, for example, either syllabic or consonantal allomorphs, would be specifically impaired. For this, we need more precise accounts of the processes on which the adjustment of morphemes to the phonological context depends.

However, two additional predictions can be derived from the partial specification hypothesis. Both predictions follow from the assumption the hypothesis makes about morpho-phonological processes: that there are processes applying only to phonological features involving morphological elements. A first prediction is that phonological features could be impaired when associated with morphology but spared otherwise. This is indeed what was revealed by TB’s contrasting responses in naming and reading. The segments /az/ and /ad/ that TB omitted in naming, when processing them as part of the allomorphs, were produced in reading by relying on print-sound transcoding procedures that bypass morphology. Further evidence, more anecdotal in nature, was found in the case of “glasses”, a word TB was able to say when it referred to spectacles but not to the plural of glass, as in a drinking utensil. Here, TB was consistently successful with the lexicalized form glasses for which no morpho-phonological processes are at play (Brinton & Traugott, 2005). A second prediction relates to phonological changes that apply more generally, without being restricted to specific morphological domains. An example of these types of changes is represented by flapping, an optional rule of American English (Patterson, LoCasto, & Connine, 2003) whereby the inter-syllabic /t/ is produced as /r/ when the preceding vowel is stressed (de Jong, 1998). Flapping occurs both with monomorphemic words like butter (/ˈbuːtər/) and multi-morphemic words like batter (/ˈbaetər/). According to the partial specification hypothesis, flapping, as a strictly phonological/phonetic process, would be expected to be preserved in language deficits affecting morpho-phonological processing; in fact, flapping occurred, without hesitation, when TB produced words like writing.

Ideally, the prediction about TB’s ability to make phonological adjustments should instead be tested by comparing phonological changes that are closely similar when triggered by morphology and those that occur in non-morphological environments. A hypothetical example would be to have a form of vowel insertion in non-morphological environments to match with syllabic allomorphs. Such a test could not be undertaken in English with TB because it does not exist.

The morpho-phonological nature of TB’s deficit lends support to the hypothesis that distinct mechanisms underlie the processing of phonological and morpho-phonological features. This hypothesis would be strengthened by deficits that are the mirror image of TB’s by selectively affecting morpho-phonological features that were intact in TB. Together, the two types of deficits would form a double dissociation. Selective morpho-phonological deficits were reported by Cohen-Goldberg, Cholin, Miozzo, and Rapp (2013) in their investigation of WRG. Unlike TB, WRG found it especially difficult to produce consonantal allomorphs that formed complex obstruent-obstruent clusters, which WRG typically produced by inserting a vowel between the stem and the suffix, as in cooked → /ˈkʊkəd/. These errors, which were instrumental in circumventing WRG’s problems with complex clusters, show that
vowel insertion was spared in WRG, unlike in TB. Crucially, complex consonant clusters were problematic in inflected words but not in monomorphemic words, so that WRG was incorrect with passed but correct with the homophone past. In essence, WRG’s deficit appears to be morpho-phonological in nature and, in this respect, resembles TB’s deficit. The complementarity of their deficits reveals that distinct morphophonological processes underlie vowel insertion and the concatenation of consonantal allomorphs, so that each process can be selectively damaged (or spared) in conditions of language deficits. As we suggested above, the dissociation of these processes possibly reflects the different types of information they involve (e.g., syllabic vs. phonemic). More generally, the contrasting deficits of TB and WRG demonstrate the variability with which morphophonological deficits could manifest themselves.

Evidence suggesting differences in the sound processing of morphologically complex and simple words is not restricted to sound errors selectively occurring in morphological environments. Differences were also demonstrated with laboratory measures of normal speech that analyzed intergestural timing (Cho, 2001), interconsonantal t-deletions in English connected speech (Hay, 2003), phoneme duration (Sugahara & Turk, 2009; Walsh & Parker, 1983), and effects of phoneme similarity on word production times (Cohen-Goldberg, 2013). Together, neuropsychological and laboratory evidence implies that morphological structure is a type of information encoded in word production that affects a variety of mechanisms in sound processing. How word morphology is encoded has been a topic of intense debate in psycholinguistics (see, e.g., Pinker & Ullman, 2002; Seidenberg & Gonnerman, 2000). The challenge that current evidence raises for theories of language production is one of understanding not only the format of morphological information, but also how this information can affect sound processing. Pursuing this challenge demands we pay more attention to morpho-phonology, and that we do so in both neurolinguistics and psycholinguistics.

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Disclosure Statement

No potential conflict of interest was reported by the authors.

References


Notes

1. We were unsuccessful in eliciting present, 3rd person singular verb forms (e.g., walks) with a similar procedure, using the words “Everyday he ____” as a prompt. TB would almost always produce the -ing form (“is walking”). We had expected to replicate the results with noun plurals, with which the verbs share the allomorphs -/z/, -/s/ and -/z/. TB’s problems with 3rd person singular verb forms led us to discontinue any testing of them.

2. There was also evidence of schwa deletion, another optional phonological/phonetic rule occurring in American English, particularly in some phonological environments (e.g., post-stress, word medial positions; camera: /ˈkæmərə/ → /ˈkæmərə/ (Bürki & Gaskell, 2012; Davidson, 2006; Patterson et al., 2003). We found the recording of 18 words that TB produced, without hesitation, in which schwa deletion was found to occur more than 50% of the time in a large corpus of conversational speech (Patterson et al., 2003). Examples include broccoli, chocolate, and camera. Schwa deletions occurred with 9/18 words (50%). These results further demonstrate TB’s ability to make phonological/articulatory adjustments.

Everyday he ____. In essence, WRG’s deficit in this respect, resembles TB’s deficit. The complementary nature, vowel insertion was spared in WRG, unlike in TB. Crucially, complex consonant clusters were problematic in inflected words but not in monomorphemic words, so that WRG was incorrect with passed but correct with the homophone past. In essence, WRG’s deficit appears to be morpho-phonological in nature and, in this respect, resembles TB’s deficit. The complementarity of their deficits reveals that distinct morphophonological processes underlie vowel insertion and the concatenation of consonantal allomorphs, so that each process can be selectively damaged (or spared) in conditions of language deficits. As we suggested above, the dissociation of these processes possibly reflects the different types of information they involve (e.g., syllabic vs. phonemic). More generally, the contrasting deficits of TB and WRG demonstrate the variability with which morphophonological deficits could manifest themselves.

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