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The interface between morphology and phonology: Exploring a morpho-phonological deficit in spoken production

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ABSTRACT

Morphological and phonological processes are tightly interrelated in spoken production. During processing, morphological processes must combine the phonological content of individual morphemes to produce a phonological representation that is suitable for driving phonological processing. Further, morpheme assembly frequently causes changes in a word's phonological well-formedness that must be addressed by the phonology. We report the case of an aphasic individual (WRG) who exhibits an impairment at the morpho-phonological interface. WRG was tested on his ability to produce phonologically complex sequences (specifically, coda clusters of varying sonority) in heteromorphemic and tautomorphemic environments. WRG made phonological errors that reduced coda sonority complexity in multimorphemic words (e.g., passed → [pæstɪd]) but not in monomorphemic words (e.g., past). WRG also made similar insertion errors to repair stress clash in multimorphemic environments, confirming his sensitivity to cross-morpheme well-formedness. We propose that this pattern of performance is the result of an intact phonological grammar acting over the phonological content of morphemic representations that were weakly joined because of brain damage. WRG may constitute the first case of a morpho-phonological impairment—these results suggest that the processes that combine morphemes constitute a crucial component of morpho-phonological processing.

1. Introduction

By means of largely predictable changes in word form, the morphological system allows speakers to expand word meaning, coin novel words, and allows syntactic features to surface in speech. Descriptively, the function of morphology is to govern the combination of morphemes, the meaning-bearing units of language. Morphological processes determine, for example, that the features {cat, plural} are best expressed in English by *cat* and *-s* while the features {mouse, plural} are best expressed by *mice*. Given the central role of morphology in speaking, it is essential that processing theories of language production include accounts of morphological mechanisms.

A variety of issues pertaining to morphology remain hotly debated in the psycholinguistic literature—most notably, the extent to which morphologically complex words are represented in a decomposed or whole-word format (Butterworth, 1983; Bybee, 1995; Elman, 2004; Fiorentino & Poeppel, 2007; Marslen-Wilson & Zhou, 1999; Rubin, Becker, & Freeman, 1979; Seidenberg & Gonnerman, 2000; Stockhall & Marantz, 2006; Taft, 2004) and whether morphological knowledge is instantiated by one or two processing routes (Burzio, 2002; Clahsen, 1999; Halle & Marantz, 1993; Joanisse & Seidenberg, 1999; Miozzo, 2003; Pinker,

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1999; Rumelhart & McClelland, 1986; Ullman, 2001). Despite these debates, theories of spoken production generally share a *compositional* view, which proposes that morphemes are distinctly represented and that morphologically complex words are assembled from individual morphemes (Dell, 1986; Levelt, Roelofs, & Meyer, 1999). Although these accounts do not rule out the possibility that some morphologically complex words are represented in an undecomposed fashion as whole words, the basic claim is that morphological composition remains a key process in production. The evidence for compositionality in spoken production comes from a variety of sources including speech errors (Garrett, 1975; Garrett, 1980; Stemberger, 1982), reaction time tasks (Bien, Levelt, & Baayen, 2005; Janssen, Roelofs, & Levelt, 2002; Janssen, Roelofs, & Levelt, 2004; Roelofs, 1996; Roelofs & Baayen, 2002) and acquired language impairments (Badecker, 2001; Cholin, Rapp, & Miozzo, 2010; Miceli, Capasso, & Caramazza, 2004). In the present work, we specifically investigate the implications of compositional morphological processing for the encoding of the phonology of multimorphemic words. That is, we examine word production at the morphology–phonology interface.

1.1. Morpheme integration and phonological processing

In spoken production, there is an intimate link between morphological and phonological processing. First and foremost, the output of morphological operations serves as the input to phonological processes. When morphological processes combine lexical representations (morphemes) to form a multimorphemic word, the constituent sounds must also be combined in such a way that the resulting phonological representation is suitable for driving spoken production. For example, once the morphemes *cat* and *-s* have been selected, the phoneme sequences /kæt/ and /s/ must be combined into /kæts/ in order to allow subsequent phonological processing to take place. This assembly process, though currently underspecified in theories of spoken production, likely involves—at the very least—updating segmental position information to reflect the newly constructed multimorphemic environment (e.g., the /k/ in *cloth* is no longer in word-initial position when it appears as part of the compound *tablecloth*). Whatever specific operations this process may entail, the integration of the phonological content of a word's morphemes is crucial to the ability of downstream processes to operate over the word.

The second reason that morphological and phonological processing are intimately related in production is because the combination of morphemes frequently results in the creation of new phonological environments that vary in how well they conform to universal and language-specific phonological constraints. In many cases, the phonological environment created by combining morphemes must be overtly modified by the phonology in order to satisfy a language's phonological constraints. For example, affixation in English frequently requires the phonological content of morphemes to be resyllabified in order to create optimal syllables (*find* + *ing* = [faɪn.dɪŋ]). Far more dramatic modifications also abound—for example, in languages containing vowel harmony rules, root and affix vowels are modified so that they agree in particular features. In Turkish, suffix vowels must agree with root vowels in backness and rounding. Thus, the phonetic form of the genitive suffix depends on the features of the root vowel: [es-i̲n] 'spouse-GEN' but [tur-u̲n] 'tour-GEN'. In languages with consonant dissimilation rules, the merger of morphemes may cause root and affix consonants to be modified so as to not share features (e.g., Tashlhyit Berber dissimilation causes prefixes to delabialize before roots containing a labial consonant: /m-fara/ → [n-fara] 'REFLEXIVE-disentangle'; Alderete, 2003).

In other cases, morpheme combination does not trigger overt changes to a word's phonological form (e.g., *unique* + *-ness* = *uniqueness*), but instead involves changes to the word's phonological well-formedness. For example, *uniqueness* contains a metrical configuration known as 'stress clash', where stress appears on adjacent syllables: [ju.ník.nὲs]. Stress clash, though it requires no modification when it involves the suffix *-ness*, is generally dispreferred (marked) in English, as demonstrated by its rarity in monomorphemic words (Hammond, 1999). The merger of *unique* and *-ness* thus results in a word with a relatively low degree of phonotactic well-formedness. Another example of a change in phonological well-formedness can be seen in the case of the English past tense. When combined with consonant-final roots, the past tense suffix *-ed* creates consonant clusters of varying sonority profiles, either obstruent–obstruent coda clusters (e.g., *walked* [wa<u>kt</u>]) or sonorant–obstruent clusters (e.g., *spanned* [spæ<u>nd</u>]). Both sonority profiles are tolerated in English and appear in monomorphemic words (e.g., *act*, *band*), however while sonorant–obstruent codas are common both in English monomorphemic words and across languages, obstruent–obstruent codas are relatively infrequent in English monomorphemic words and are cross-linguistically marked, suggesting that the latter profile is relatively less well-formed than the former (Clements, 1990; Hammond, 1999).

It is likely that these changes in well-formedness have a substantial influence on phonological processing. Evidence from normal and brain-damaged individuals indicates that phonological processes are sensitive to phonological well-formedness (often referred to as phonological complexity) (e.g., Buchwald, 2009; Goldrick & Rapp, 2007; Janssen & Domahs, 2008; Laganaro, 2005; Romani & Calabrese, 1998; Romani & Galluzzi, 2005; Stenneken, Bastiaanse, Huber, & Jacobs, 2005; Vitevitch, Armbrüster, & Chu 2004), suggesting that words that are less well-formed as a result of morpheme combination may strain phonological processes more than words that are relatively more well-formed. Thus, conditions where morphemes are combined create environments that are taxing for the phonology and may provide an opportunity to investigate the morphology–phonology interface.

1.2. Morpho-phonological deficits

The two aspects of the relationship between morphology and phonology outlined above – the fact that morphological processes stitch together representations that phonological processes must act over and the fact the combined morphemes frequently create changes in phonological well-formedness that phonological processes are sensitive to – raises the possibility of impairments that are specific to the interface of morphology and phonology. In the following sections, we describe the properties that are likely to characterize morpho-phonological deficits and discuss how they differ from deficits reported in previous investigations. In this paper we will describe the case of an individual who, we will argue, has a clear morpho-phonological deficit (although this is not the only deficit that he suffers from).

1.2.1. Locus of impairment

Theories of spoken production generally distinguish between earlier 'lexical' and later 'post-lexical' stages of phonological processing (see Fig. 1). Briefly, the early 'lexical phonological processes' are morpheme-based and involve the retrieval of the phonological representations of morphemes and their assembly. These phonological representations then serve as input to a series of post-lexical processes. Collectively, post-lexical processes are responsible for preparing a word's phonological form for production. Theories of spoken production typically hold that post-lexical processing involves at least two types of processing: phonological retrieval/encoding, where processing occurs primarily over segmental representations, and phonetic encoding, where processing occurs primarily over articulatory gestures (Buchwald & Miozzo, 2012; Cholin & Levelt, 2009; Goldrick & Rapp, 2007; Laganaro & Alario, 2006; Levelt et al., 1999; Romani, Galluzzi, Bureca, & Olson, 2011). The post-lexical stage is also thought to encompass processes based in the phonological grammar, which make any adjustments that are allowed by the language in order to maximize phonological well-formedness. Subsequently, there are further processes that specify a variety of parameters that make it possible to implement a motor representation and, ultimately, its articulation. Within this framework, we assume that morpho-phonological deficits arise in the transition between the morpheme-based lexical stages and the segment-based post-lexical stages of phonological processing.

1.2.2. Types of errors

As described earlier, morpho-phonological processing involves computing those aspects of a word's phonological form that relate to its morphological structure. As such, errors resulting from a morpho-phonological impairment should: (a) primarily involve sounds as opposed to whole

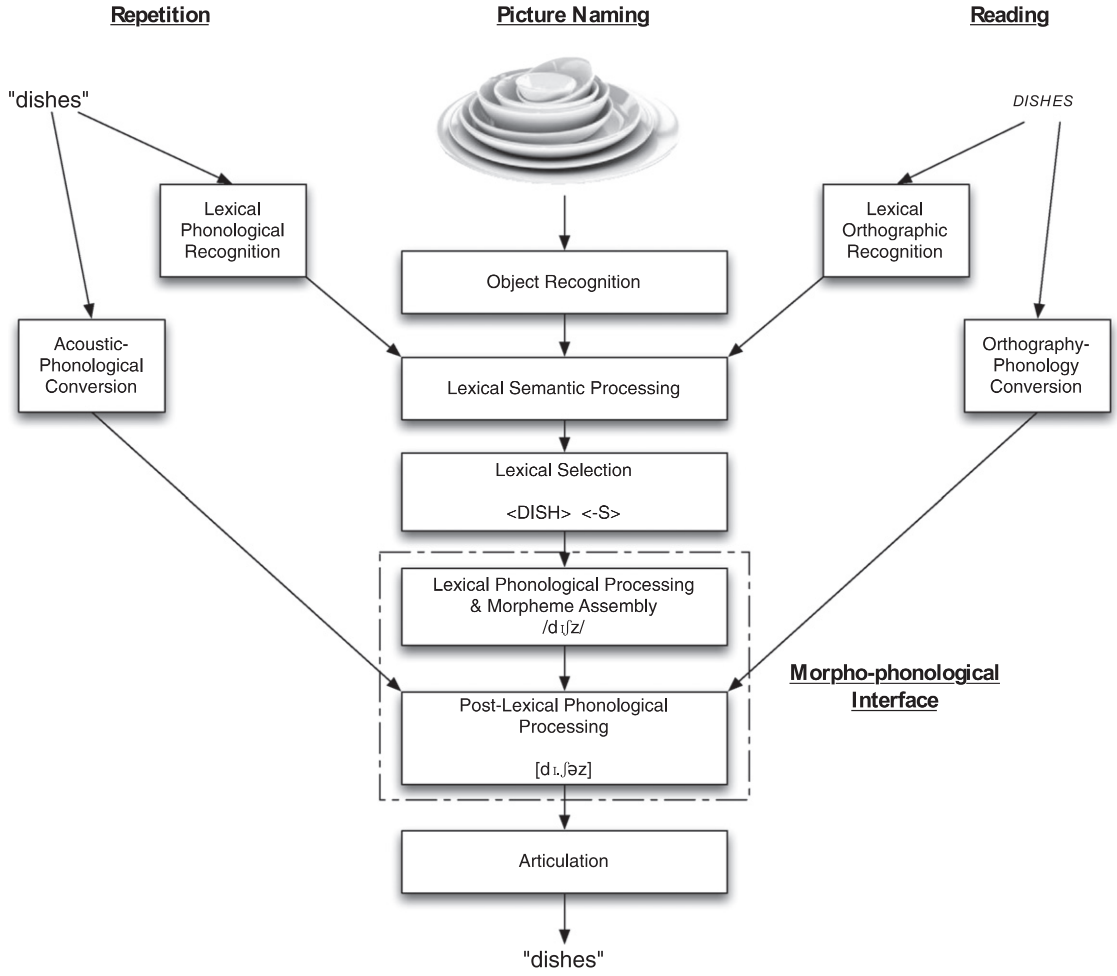

Fig. 1. The cognitive architecture of the spoken production system, adapted from Goldrick and Rapp (2007).

morphemes, (b) be influenced by the complexity/markedness of the phonological environment that results from combining the morphemes (e.g., consonant clusters or metrical patterns created through affixation or compounding, etc.), and (c) at least under certain conditions, errors should reduce complexity/markedness of the response relative to that of the target structure.

More specifically, we expect that errors should primarily affect multimorphemic words and should occur most frequently in the environment at or near the juncture between morphemes. Monomorphemic words, which neither contain morphological structure nor require morphological assembly should be spared (at least in the pure form of this deficit). Additional predictions concern the word production tasks in which errors affecting multimorphemic word should appear. We expect errors in tasks that require the combination of lexically retrieved morphemes, but not in tasks in which morpheme combination can be by-passed (e.g., in tasks which can be performed entirely sub- or non-lexically). As we discuss in detail later, naming and repetition are, respectively, examples of tasks exhibiting these contrasting characteristics.

1.2.3. Contrast with other impairments

Our proposed characterization of morpho-phonological deficits contrasts with previous descriptions of acquired speech deficits involving phonological and/or morphological errors. For example, a number of investigations have described errors involving segments (dog → [dæg]) or difficulties with prosodic features (e.g., stress; cigár → cígar), and many of these reports have also demonstrated that phonological complexity affected the occurrence of segmental errors (Buchwald, 2009; Buchwald & Miozzo, 2011; Cappa, Nespor, Ielasi, & Miozzo, 1997; Goldrick & Rapp, 2007; Romani & Galluzzi, 2005). On this basis, these types of errors have typically been interpreted as arising from deficits affecting phonological and/or phonetic mechanisms. Critically, these errors occurred in monomorphemic and multimorphemic words alike, making them unlike errors that are predicted to result from morpho-phonological deficits. Other investigations have documented errors involving entire morphemes, their deletion (cooks → cook) or substitution (cooks → cooking) (Badecker & Caramazza, 1991; Miceli et al., 2004; Miozzo, Fisher-Baum & Postman, 2010). Although these morpheme-based errors have typically co-occurred with phonological/phonetic errors, in none of these cases have the phonological/segmental errors been reported as occurring primarily at morpheme boundaries. On that basis, these deficits are not consistent with our characterization of morpho-phonological impairment.

1.2.4. Impairment profiles

We now consider the question: what set of cognitive processes, when damaged, would give rise to the pattern of performance characterizing a morpho-phonological deficit? Two possibilities seem likely: a deficit arising from damage to lexical processes and a deficit arising from damage to post-lexical processes. We now consider these proposals in turn.

As discussed above, once a morphologically complex word's morphemes have been selected, lexical processes must combine their component phonemes to form a unified phonological representation. Damage to lexical processes could impair this assembly operation, resulting in phonological representations that are weakly/improperly joined at morpheme boundaries. In this situation, the ability of *intact* post-lexical processes to compute the phonological form of the word may be reduced, leading to phonological errors.

A morpho-phonological impairment could also arise as a result of damage to post-lexical processes. Generative theories of phonology have long proposed that the grammar contains components (e.g., rules/constraints) that specifically relate to morphological structure (e.g., 'Derived Environment Effects'; Chomsky & Halle, 1968; Kiparsky 1982; Prince & Smolensky, 1993). Damage to these components of the grammar would be expected to result in phonological errors that relate primarily or specifically to the phonological processing of multimorphemic environments.

To summarize, a morpho-phonological impairment could arise as a result of two complementary patterns of impairment: (1) impaired lexical processing with intact post-lexical processing and (2) intact lexical processing with impaired post-lexical processing. In the former case, impaired lexical processes are assumed to produce improperly/weakly combined phonological representations that reduce the accuracy of intact and otherwise well-functioning post-lexical processes. In the latter case, intact lexical processes produce properly combined phonological representations but damaged post-lexical processes (specifically, those involved in computing the phonological form of multimorphemic words) produce errors. Both damage profiles (in their pure form) are expected to result in errors primarily or exclusively in multimorphemic words and both are likely to result in surface forms that are more well-formed than their targets.

2. Present investigation

We report on the case of a brain-damaged individual, WRG, who presented with severe difficulties in spoken production. We first show that the neural damage has disrupted (morpheme-based) lexical processing while leaving post-lexical phonological processing relatively intact. We go on to show that WRG produces phonological errors in multimorphemic words that are sensitive to the phonological complexity that is produced by combining morphemes. We also show that his errors reduce the phonological complexity of the word and are restricted to the region of the morpheme boundaries. Finally, we show that this sensitivity to phonological complexity is not observed in mono-morphemic environments. Based on these findings, we argue that WRG exhibits a deficit that displays the characteristic features of a morpho-phonological deficit as proposed above: difficulty producing phonologically marked forms when they occur in morphologically complex contexts. In terms of the specific functional locus of the impairment, we argue that WRG's deficit is most consistent with an impairment affecting his ability to assemble the phonological content of morphemes and that his errors arise from an intact phonological grammar acting over weakly-joined representations. WRG thus represents the first documented neuropsychological case of a clear morpho-phonological deficit and analysis of his performance allows us to shed light on the processes operating at the morphology–phonology interface.

2.1. Case report: WRG

WRG's case has been previously described in Cholin et al. (2010) and Miozzo, Costa, Hernández, and Rapp (2010). WRG was born in Germany and grew up speaking German as his native language. At the age of 8, he moved to China and attended an English-speaking international school until the age of 18, when he moved the United States. He subsequently completed college, earned a law degree, and worked as an accountant until his retirement. English became WRG's dominant language, and he used it proficiently both at work and at home.

WRG suffered a stroke in 2004 that affected the area of the distribution of the left middle and posterior cerebral arteries. The present investigation began 2 years after the stroke, when WRG was 76 years old, and continued for about a year (during which time his cognitive profile remained stable).

The stroke severely affected WRG's spontaneous speech, limiting him mostly to short utterances that were produced with much effort. By contrast, WRG's single word comprehension remained essentially intact, as evidenced by a standard score of 98 (45th percentile) in the auditory version of the PPVT (Form L; Dunn & Dunn, 1981). This task requires matching a spoken word to a target picture presented along with semantically related picture foils. WRG's ability to discriminate among semantically related pictures reveals preserved visual processing and generally intact lexical semantic knowledge.

The data presented below provide background information to characterize WRG's deficits in word production and reading and to help identify tasks suitable for examining his word production in greater detail.

2.1.1. Determining the locus of WRG's spoken production impairment

As can be seen in Fig. 1, picture naming and repetition tasks are both assumed to require post-lexical phonological processing, while only picture naming additionally requires lexical phonological processing (it is believed that repetition may be accomplished via lexical and non-lexical processing; Hanley, Kay, & Edwards, 2002; Nozari, Kittredge, Dell, & Schwartz, 2010). On this basis, it has been proposed that performance in naming and repetition can be used to identify the locus of damage in the spoken production system (Goldrick & Rapp, 2007). For example, spared repetition in the face of impaired picture naming indicates impaired lexical phonological processing and relatively intact post-lexical processing. In contrast, similar errors in repetition and naming indicate impaired post-lexical processing. On this basis, WRG's performance in naming and repetition was evaluated in order to identify the primary locus of his spoken production impairment.

WRG's performance in picture naming gives an indication of the limitations of his spontaneous speech. He correctly named only 12% of the 115 pictures from the Berndt et al. set (Berndt, Mitchum, Haendiges, & Sandson, 1997) that depicts nouns and verbs matched for frequency. Only the first complete response was scored in all tasks reported in the present investigation. His naming was equally poor with nouns and verbs (13% vs. 10%; $\chi^2(1, N = 115) = .17$, $p > .05$). There was a non-significant trend for the correctly named items to be shorter than the incorrectly named items (3.3 phonemes vs. 4.1, $t(113) = 1.7$, $p = .08$). The nature of WRG's naming errors further illustrates the severity of his naming impairment: non-words bearing no resemblance to their targets (e.g., ear → [gækəs], door → [nagidə], iron → [wuz], fence → [stʊk], window → [gald], moon → [bɔgəlməs]) were the most common errors (47%), followed by unrelated words (16%). Of the remaining errors, 12% were perseverations, 11% were phonologically related words/non-words (⩾50% of phonemes shared with the target), 6% were semantically related words, and 9% were 'other' responses (e.g., no response, non-naming responses like "moo" instead of cow).

In contrast to his poor naming accuracy, WRG performed extremely well in repetition, correctly repeating 89% of 113 monomorphemic words presented in this task. Since his repetition errors consisted of 1- or 2-segment phonemic distortions (e.g., ambush → [æmbʊs], bide → [baɪnd], fact → [fæt], bandage → [brɛndɪʤ], burden → [bɝd]), phoneme accuracy provides a more precise measure of his repetition abilities; WRG correctly produced 97% of all phonemes in repetition. WRG's repetition accuracy was not affected by word length (monosyllabic ($N = 57$): 89%; disyllabic ($N = 56$): 89%) or frequency (low frequency: 91%, high frequency: 88%; $\chi^2(1, N = 113) = .26$, *n.s.*). Furthermore, the dissociation between WRG's extremely low accuracy in picture naming and good performance in repetition cannot be explained by the characteristics of the words tested in each task. In comparison with the words administered for repetition, the words of the picture naming task were shorter (mean phonemes: 4.0 vs. 4.6; $t(226) = 3.21$; $p < .01$), more frequent (log lemma freq: 1.6 vs. 1.3 $t(226) = 2.56$; $p < .05$) and came from larger phonological neighborhoods (13.2 vs. 9.8; $t(226) = 2.3$; $p < .05$), features that should have conferred a processing advantage to picture naming (e.g., Goodglass, Kaplan, Weintraub, & Ackerman, 1976; Rochford & Williams, 1965; Vitevitch et al., 2004). (Frequency norms were obtained from Baayen, Piepenbrock, & Gulikers, 1995, and neighborhood norms were from Sommers (2002).)

In the context of the functional architecture depicted in Fig. 1, WRG's good performance in word comprehension indicates that his word production difficulties arose subsequent to the level of lexical semantic processing. Further, generally good performance in repetition effectively rules out post-lexical and/or motor planning deficits as the principal source(s) of his word production difficulties. Together, the results from comprehension, repetition, and picture naming point to a deficit arising between lexical semantic processing and post-lexical phonological processing—namely, in lexical retrieval (L-level selection) and/or lexical phonological processing. This conclusion is further supported by the results of the elicitation tasks used in Experiments 1 and 3 (described in more detail below). Briefly, in these experiments WRG was presented with short incomplete sentences that he completed producing suffixed words. For example, in Experiment 1, in which verbs were tested, WRG completed the sentence by saying the past tense of the verb (e.g., "Today I *walk*. Yesterday I [walked]"). In Experiments 1 and 3, WRG was presented with regular/productive and irregular/non-productive forms. The tested forms were regularly inflected verbs (*walked*, *painted*) and irregularly inflected verbs (*sat*, *broken*) in Experiment 1, and derived nouns carrying a productive suffix (*-ness*; *blindness*) or a non-productive suffix (*-ity*; *opacity*) in Experiment 3. The results indicate that WRG was significantly more impaired with irregular/non-productive forms compared to regular/productive forms (verb accuracy: 56% vs. 23%; $\chi^2(1, N = 794) = 87.9$, $p < .0001$; nouns: 51% vs. 29%; $\chi^2(1, N = 431) = 19.7$, $p < .0001$). Since irregular and non-productive forms are unpredictable and thus most likely stored lexically, the production of these forms in the elicitation task depends on the availability of lexical information. Lexical information, however, is not as crucial with regular and productive forms, which can be produced by appending the productive suffix (*-ed*; *-ness*) to the phonological forms of the stems provided in the elicitation task. This difference in lexical retrieval demands explains why irregular and non-productive forms are both particularly susceptible to deficits affecting lexical retrieval.

2.1.2. Word reading

Reading aloud was also tested in detail, to determine if the lexical route of reading was at least partially available, in which case reading could be used as a task to investigate lexically-based morpheme processing. As depicted in Fig. 1, following the initial recognition of the written letter strings, the lexical reading route utilizes the same processes as spontaneous speech to compute the meaning and sounds of words. An alternative pathway – orthography-to-phonology conversion – translates written sequences into their corresponding phoneme sequences, by-passing the lexicon. This non-lexical route is essential for non-word reading, while the lexical route is necessary for reading words with irregular (unpredictable) spellings. Superior performance with words with regular vs. irregular spellings is typically a hallmark that the non-lexical route is playing a major role in word reading; conversely, comparable performance on words with regular and irregular spellings indicates that the lexical route is playing a major role. Accordingly, words varying in regularity and non-words were used to assess the integrity of WRG's lexical and non-lexical routes, respectively.

WRG's oral reading was impaired (42/60, 70% correct) but his performance did not differ for regularly (20/30) and irregularly spelled words (22/30; PALPA, subtest 35; Kay, Lesser, & Coltheart, 1992). WRG's word reading was affected by word frequency, as demonstrated by a significant correlation between accuracy and frequency ($r = .21$; $p = .01$; analysis based on 100 words). WRG's word reading errors consisted mostly of word and non-word responses that were phonologically/orthographically related to the target word (e.g., stench → stern, barge → [marʤ]). WRG's ability to read non-words was also impaired (14/24, 54% correct; PALPA, 36; Kay et al., 1992) and his errors included lexicalizations, the types of incorrect responses expected when the non-lexical route is unavailable and the lexical route is used instead. Together, the impaired non-word reading, the lexicalization errors with non-words, the lack of regularity effect with words, and the frequency effect indicate that WRG utilized the (albeit impaired) lexical route in reading.

3. Experiment 1: coda sonority in heteromorphemic environments

As discussed above, the hallmark feature of a morpho-phonological deficit would be difficulty in the production of multimorphemic words that varies as a function of the phonological complexity created by morpheme combination. To evaluate this possibility, in Experiment 1, we examined WRG's ability to produce inflected words in which the joining of stem and inflectional suffix resulted in sonority profiles of different degrees of markedness. A second objective of Experiment 1 was to provide further information regarding the locus of WRG's impairment. Damage to the processes that combine the phonological content of different morphemes is expected to occur 'early' in the stream of phonological processes supporting production (Fig. 1). This prediction was tested in Experiment 1 investigating the effects of coda variation in tasks requiring lexical processing (elicitation and reading) and in a task that does not require lexical processing (repetition). Damage to 'early' lexical phonological processes would cause difficulties only in tasks that require this level of processing.

Although sonority has proven difficult to define in acoustic/articulatory terms, it can be roughly described as characterizing how 'vowel-like' a segment is (Keating, 1983; Lindblom, 1983). Glides are considered to be the most sonorous consonants, followed in order of decreasing sonority by liquids, nasals, fricatives and finally, stops. Two broad classes based on sonority are defined: obstruents, which are stops and fricatives, and sonorants, which are everything else. Sonority has long been held to be important in governing the shape of syllables across the world's languages (see Clements, 1990 and the references therein). Furthermore, certain syllabic sonority profiles are preferred and therefore tend to be frequently observed cross-linguistically as well as amongst the words of a specific language. In general, languages prefer for sonority to rise in onsets (e.g., /tr/) and fall in codas (e.g., /rt/). An example of the coda preference is provided by English where codas consisting of a sonorant followed by an obstruent (SO coda; e.g., *felt*, *band*, *port*) are more common than those containing two obstruents (OO codas; e.g., *fist*, *apt*, *pact*).[1] It is generally assumed that the phonological grammar encodes this hierarchy and, therefore, to the extent

[1] Counting by types, 34/48 (71%) of all possible SO codas are attested in English. It is less straightforward to calculate a similar figure for OO codas since they are subject to a number of phonotactic restrictions (these restrictions may themselves be an indication of the fact that OO codas are generally dispreferred). In the most liberal assessment (which assumes that apart from /sp/ and /sk/, OO codas can only consist of a voiceless stop or fricative followed by a voiceless coronal stop or fricative; Hammond, 1999), only 9/20 (45%) of all phonotactically possible OO codas are attested in English.

to which the production system is sensitive to grammatical constraints and pressures, spoken productions will exhibit evidence of this hierarchy. Consistent with this, young children (McLeod, van Doorn, & Reed, 2001) found SO codas easier to produce than OO codas. With WRG we examined the effects of sonority by testing stem + inflection combinations that resulted in either SO codas (*killed*) or OO codas (*shrugged*).

3.1. Methods

To investigate WRG's ability to produce inflected words varying in coda sonority, we tested regular past tense verbs and regular past participle verbs in three oral word production tasks: elicitation, reading, repetition. The inflected verbs were mono- and disyllabic and ended in an SO cluster (*killed* [kɪld]) or an OO cluster (*shrugged* [ʃrʌgd]). The numbers of SO and OO verbs were, respectively, 103 and 190 in elicitation, 37 and 45 in reading, and 31 and 41 in repetition. These regular past tense and past participle verb forms were tested along with two other types of past tense and past participle verbs: (a) irregularly inflected verbs (*wove*, *written*) and (b) regularly inflected verbs taking syllabic inflections (*started*). These other verbs comprised 34% of the verbs presented in elicitation, 75% in reading, and 73% in repetition, and were introduced to diversify the phonological material at the ends of words. Furthermore, because the regular/irregular distinction in the past and past participle tenses is lexically based, the presentation of regular and irregular forms would encourage lexical access (at least in elicitation).

Sentence frames were verbally presented by the experimenter to elicit the past tense ("Today I <verb>. Yesterday I ______".) and the past participle ("Today I <verb>. In the past I have ______".). The stimulus verb was embedded in the sentence frame and WRG was instructed to orally complete the sentence with the appropriate form of the verb. To facilitate WRG's response, the sentence frames (only) were also presented in written form. To avoid tense confusions, the past tense and past participle were tested during different testing sessions in the elicitation task). Since this was not relevant for reading and repetition, in these tasks the stimuli for the two tenses were mixed in the same lists. In the reading task, single inflected verbs (without a sentence frame) were presented in lowercase one at a time for WRG to read aloud. In the repetition task, single inflected verbs were orally presented one at a time for WRG to repeat immediately. In the repetition task, the experimenter re-presented a stimulus upon WRG's request. All of WRG's responses were immediately transcribed by the experimenter and were later checked against an audio recording for accuracy.

3.2. Results

Unless specifically indicated, results refer to those obtained for trials involving regular past tense or past participle forms that do not require a syllabic *-ed* inflection. In terms of overall accuracy, WRG responded significantly more accurately to SO than OO verbs in elicitation (75% vs. 48%; $\chi^2(1, N = 293) = 19.0$, $p < .0001$) but not in reading (59% vs. 40%; $\chi^2(1, N = 82) = 3.1$, $p = .08$) or repetition (77% vs. 68%; $\chi^2(1, N = 72) = .73$, $p > .05$). It is important to note that overall accuracy does not necessarily demonstrate sensitivity to coda sonority, however, since it also reflects the ability to produce segments in positions other than the coda. For that reason, further analyses were conducted to specifically examine WRG's ability to produce the stems and codas of words varying in their sonority profiles.

In a first analysis we examined WRG's accuracy and error types on the codas created from morpheme combination. In all three tasks, WRG's errors were highly similar to the targets and, as a result, codas could be confidently identified and scored, even when the rest of the word contained errors (the only exception were 9 OO and 1 SO responses from the elicitation task that were too distant from the target and were consequently removed from the analysis). In terms of accuracy, the results mirrored those of the overall analysis: SO codas were correctly produced significantly more frequently than OO codas in elicitation (82% vs. 58%; $\chi^2(1, N = 283) = 16.35$, $p < .0001$) but not in reading (76% vs. 55%; $\chi^2(1, N = 82) = 3.6$, $p = .06$), or repetition (81% vs. 83%; $\chi^2(1, N = 71) = .01$, $p = .92$).

WRG's coda errors were then examined in detail. WRG made four kinds of errors involving codas: (1) no suffix (e.g., walloped → wallop); (2) wrong suffix (e.g., walloped → walloping); (3) stem-final deletion (responses in which the final consonant of the stem was deleted; e.g., walloped → [walət]); and (4) coda insertions (i.e., responses in which phonological material was inserted into the coda, either between the stem and the suffix or after the suffix; e.g., walloped → [waləpɪd], walloped → [waləpdɪd]). Across reading and elicitation, 44% of the coda insertions consisted of just a vowel and the remainder consisted of a vowel and a consonant. Examples of these errors are presented in Table 1. Coda insertion errors will be referred to as 'post-stem insertions' so that the same terminology can be used in Experiment 3. As shown in Fig. 2, post-stem insertions were more likely to occur with OO than SO codas, both in elicitation responses (27% vs. 5%; $\chi^2(1, N = 283) = 20.76$, $p < .001$) and reading responses (27% vs. 5%; $\chi^2(1, N = 82) = 6.48$, $p = .01$). In sharp contrast to what was observed in these two tasks, no coda insertions were recorded in repetition. The other kinds of errors (no suffix, wrong suffix, stem-final deletion) were produced with comparable frequencies in OO and SO codas in all three tasks (Fisher Exact Test *p*-values for these error types ranged from .12 to 1).

An analysis of stem accuracy was conducted with two-fold motivation. The first reason was to determine if WRG's ability to produce stems affected the phonological well-formedness of codas. The second reason related to the fact that the OO and SO words had not been matched on stem frequency, phoneme length, or neighborhood density, variables known to affect word production in conditions of language deficits. If WRG's word production were sensitive to these variables, we should observe their effects on stem production. Analysis of the results revealed that accuracy was similar for SO and OO stems in elicitation (90% vs. 86%; $\chi^2(1, N = 288) = .9$, $p = .34$) and reading (84% vs. 78%; $\chi^2(1, N = 82) = .47$, $p = .49$). In repetition, WRG was significantly worse on stems from OO words than SO words (accuracy: 78% vs. 97%, Fisher Exact Test $p = .04$). Although it is not immediately clear why this result was

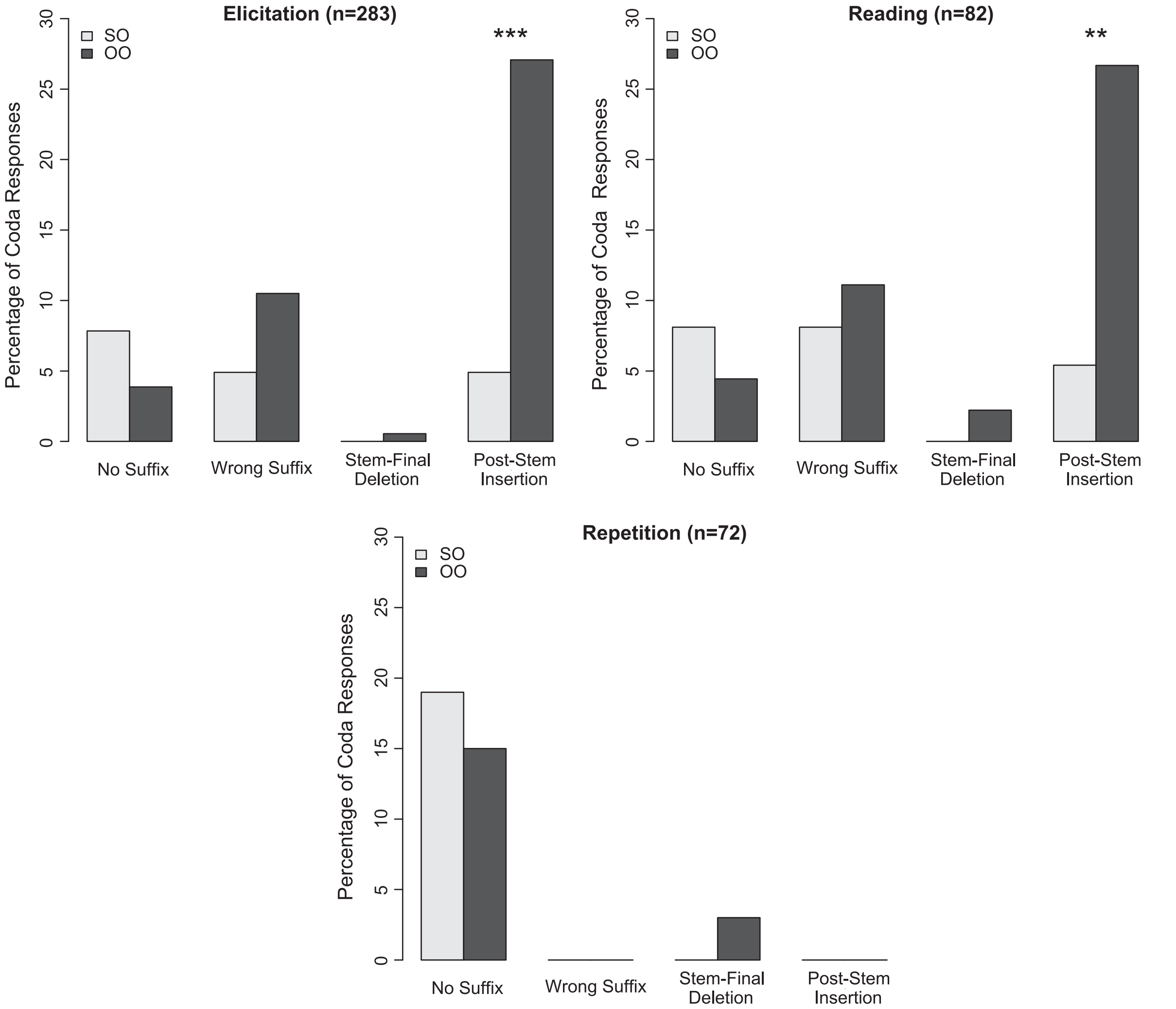

Fig. 2. WRG's coda errors on regular verbs inflected for the past tense/participle. 'SO' indicates a verb ending in a sonorant–obstruent coda (e.g., *banned*); 'OO' indicates a verb ending in an obstruent–obstruent coda (e.g., *packed*). $^{**}p = .01$; $^{***}p < .001$.

Table 1
Representative coda errors made in Experiment 1.

Error Type	Target	Response
Post-stem insertion	Passed	[pæstɪd]
	Cooked	[kʊkɪd]
	Rolled	[roldɪt]
	Stabbed	[stæbɪt]
	Slipped	[slɪptɪd]
	Derived	[dəraɪvdɪd]
	Nagged	[nægdɪt]
	Washed	[waʃtɪt]
Wrong suffix	Marched	[marʧɪz]
	Tugged	[tʌgɪn]
	Trespassed	[trɛspæsɪz]
No suffix	Opened	[oʊpɪn]

obtained in repetition, the fact that 6/9 of his OO stem errors in the repetition task were single phoneme substitutions suggests that the errors may have resulted from a mild auditory impairment. This is consistent with the relatively large number of no suffix errors observed in repetition but not in reading or elicitation – WRG may have had some difficulty perceiving individual sounds, leading to their deletion or substitution (see Fig. 2). Whatever the case, WRG's performance in repeating stems did not affect the results of the coda analysis above that indicated that there was no accuracy difference between SO and OO codas. In sum, the stem analysis reveals that the effect of coda sonority in WRG's errors did not reflect features of the word as a whole or his ability to produce the stem.

Since the stimuli used in Experiment 1 had not been controlled apart from their coda sonority, a logistic mixed-effects regression analysis was run to as a second measure to ensure that the differences in the basic psycholinguistic properties of the stimuli were not responsible for the effects attributed to coda sonority differences. For the analysis, the dependent measure was whether a response contained a post-stem insertion (1) or not (0). The following nuisance variables (from the English Lexicon Project; Balota et al., 2007) were entered in the model: the log HAL frequency of the stem (Lund & Burgess, 1996), the length of the stem in phonemes, and the stem's phonological neighborhood density. The model also included a categorical variable encoding the word's coda sonority. Finally, the model also contained random intercepts for each word and random slopes for coda sonority; this full random-effects structure allows the results of the analysis to extend to new words.

The analysis was conducted using all of WRG's elicitation and reading responses. Models were fit using the *lme4* package (Bates, Maechler, & Dai, 2008) of the statistical program R. Model comparison revealed that coda sonority significantly predicted post-stem insertions, above and beyond the influence of the other variables ($\beta = 3.86$; s.e. = 1.68; $z = 2.3$; $\chi^2(1) = 33.76$, $p < .001$), confirming that coda sonority significantly influenced WRG's post-stem insertions. A second model with frequency, length, and neighborhood density calculated for the entire word instead of the stem was run and the results were the same: coda sonority significantly predicted WRG's post-stem insertions ($\beta = 3.89$; s.e. = 1.69; $z = 2.3$; $\chi^2(1) = 35.99$, $p < .001$).

3.3. Discussion

In both elicitation and reading, WRG performed less accurately with OO than SO codas that were the products of morphological inflection. This accuracy difference was driven entirely by post-stem insertion errors, with other types of errors being produced at remarkably similar rates in SO and OO words. Inspection of the coda insertion errors themselves indicates that they simplified coda structures: of the 67 insertion errors observed in elicitation and reading, all except 4 improved the sonority profile of the cluster (the exceptions maintained the sonority profile, e.g., reached → [riʧɪst]). Insertion errors simplified the codas either by separating the coda consonants into different syllabic positions ([walə.p̲ɪd̲]) or by re-syllabifying them into different syllables ([waləp̲.d̲ɪd]). Importantly, the coda insertion errors improved the sonority profile of the codas and can thus be understood as phonological 'repairs' that, by decreasing phonotactic complexity, are consistent with the well-formedness constraints of the phonological grammar.

Why are none of these repairs observed in repetition? Repetition differs from elicitation and (lexically-based) reading in that it does not require morpheme assembly, since repetition can treat the auditory stimulus as single string, with no internal morphological structure. Thus, good performance in repetition suggests that difficulties arise only in response to the morphological structure created by combining morphemes. The sensitivity to phonological complexity precisely at the morphological boundary and the insertion of phonological material that decreases phonological complexity both indicate a robust phonological system working to improve well-formedness. The fact that these features are present in elicitation and reading and absent in repetition is consistent with a morpho-phonological deficit.

It should be noted that there are other types of errors WRG could have made that would have served to simplify coda structure. No-suffix errors (walloped → wallop) and certain wrong-suffix errors (walloped → walloping) simplify coda complexity by preventing consonant clusters from forming in the first place, while stem-final deletion errors (walloped → [walət]) simplify coda structure by deleting the first member of the cluster. However, the finding that the probability of these errors did not vary as a function of sonority indicates that they were not the product of structure-simplifying phonological repairs, but rather had a different source (we will return to this point in the General Discussion).[2]

WRG's post-stem insertion errors bear a resemblance to the double marking errors that are sometimes made by young children (Jacobson & Schwartz, 2005; Pinker & Prince, 1988; Stemberger & Bernhardt, 2001; Xu & Pinker, 1995) and aphasic individuals (Ullman et al., 1997). Could [feɪldɪd], for example, result from combining *fail* with the past tense suffix /-d/ (producing [feɪld]) and then repeating the process, appending /-d/ a second time? There are three lines of evidence that argue against this account of WRG's errors. First and most simply, many (27%) of the coda insertions did not contain phonological material that could be interpreted as double past tense/past participle morphemes. For example, rubbed → [rʌbɪt] and shrugged → [ʃrʌgɪt] contain only one phoneme ([t]) that could plausibly be considered to be a past tense/past participle morpheme. Second, according to the double marking hypothesis, the insertion errors are strictly morphological in nature, an indication that WRG was having difficulty expressing the inflectional suffix with the correct number of morphemes. If this were the case, these errors should be unrelated to phonological features such as sonority. By the same reasoning, if WRG's coda insertion errors were simply morphological, they should have been equally likely in all words, including those with stems ending in /t/ or /d/ that take the syllabic past-tense inflection (piloted → *piloteded*). The filler verbs administered in elicitation and reading whose stems ended in /t/ or /d/ ($N = 80$) provided an opportunity to test this prediction. Not a single response to these verbs contained a post-stem insertion. Although this result is unexpected according to the double-marking account, it is predicted if WRG's errors were, in fact, phonological repairs: since these items take the syllabic past-tense inflection there would be no need to insert additional phonological material. Finally, in Experiment 3, WRG made very similar insertion errors that also simplified phonological structure (see below), but in a context that did not involve the past tense. In sum, the hypothesis that post-stem insertion errors represent double marking errors receives no support. Instead, the findings are all compatible with the view that WRG's post-stem insertion errors represent phonological repairs that reduce coda complexity.

4. Experiment 2: coda sonority in tautomorphemic environments

A morpho-phonological impairment would be expected to manifest itself in the phonological environment that is

[2] It could be suspected that WRG's post-stem insertion errors resulted, in reading, from pronouncing the *-ed* morpheme according to the grapheme–phoneme conversion rules of English (walloped → [walə.pɪd̲]). Reading errors of this sort bear a resemblance to those made by individuals who rely on their sublexical reading route (Coltheart, Masterson, Bing, Prior, & Riddoch, 1983). This possibility is ruled out by the fact that WRG's post-stem insertion errors also appeared in elicitation, a task that did not involve reading.

specifically created by morpheme combination. This was confirmed by Experiment 1, where phonologically-motivated errors were observed to affect complex codas straddling the two morphemes (e.g., *passed* [pæ<u>s-t</u>]). Further confirmation was sought in Experiment 2 by investigating tautomorphemic codas, consonant sequences that lie entirely within a single morpheme (e.g., *past* [pæ<u>st</u>]). Morpho-phonological deficits are expected to leave the production of tautomorphemic codas fairly intact.

WRG's ability to produce tautomorphemic codas was tested in reading. The stimuli contained a word-final cluster, either OO ($N = 38$) or SO ($N = 122$) and consisted of three morphological types: monomorphemic (e.g. *gra<u>nd</u>*, *fa<u>ct</u>*), multimorphemic (e.g., *commonwea<u>lth</u>*, *sawdu<u>st</u>*) and irregular past-tense verbs (e.g., *su<u>nk</u>*, *swe<u>pt</u>*). All of the words contained a coda cluster in a tautomorphemic environment. The same testing procedure described for the reading task in Experiment 1 was adopted in Experiment 2.

4.1. Results

WRG's overall word accuracy did not differ between words with OO codas and words with SO codas (74% vs. 75%; $\chi^2(1, N = 160) = .01$, $p > .05$). In terms of coda accuracy, a two-tailed Fisher's exact test revealed that WRG produced the OO and SO codas themselves with equal accuracy (89% vs. 94%; $p = .46$). WRG made two types of coda errors in Experiment 2: deletions and insertions. There were only two coda deletion errors, one each on OO and SO codas. Coda insertions, which in Experiment 1 occurred at significantly different rates depending on coda sonority, did not differ across OO and SO codas (8% vs. 5%, Fisher's exact test: $p = .68$, 2-tailed).

A logistic regression analysis was conducted to evaluate whether the effect of sonority on WRG's post-stem insertion rate differed between multi- and monomorphemic words. To this end, the 82 reading trials with heteromorphemic codas from Experiment 1 and 160 reading trials with tautomorphemic codas from Experiment 2 were evaluated in a model composed of six fixed effects (coda sonority, morpheme number, coda sonority × morpheme number, (log) stem frequency, stem letter number, and density of stems' phonological neighborhoods), and random intercepts for each word and random slopes for coda sonority, morpheme number, and coda sonority × morpheme number. Model comparison revealed a significant coda sonority × morpheme number interaction term ($\chi^2(1) = 11.58$, $p < .001$), confirming that WRG's post-stem insertions were significantly more likely to vary by sonority in multimorphemic words. A second model with frequency, letter length, and phonological neighborhood density calculated for the entire word instead of the stem also found a significant interaction between sonority and morpheme number ($\chi^2(1) = 5.92$, $p < .05$).

4.2. Discussion

WRG's performance on tautomorphemic coda clusters contrasted sharply with his performance on heteromorphemic clusters. Whereas Experiment 1 revealed that post-stem insertion errors in reading in heteromorphemic environments were strongly influenced by coda sonority (SO vs. OO: 5% vs. 27%), the results of Experiment 2 indicate that, when reading tautomorphemic clusters, coda sonority did not produce differences in the rate of post-stem insertion errors (5% vs. 8%). Taken together, the results of Experiments 1 and 2 clearly demonstrate that WRG's spoken production was affected by phonological complexity only at points where morphemes combine. This is consistent with what would be expected from a morpho-phonological deficit.

5. Experiment 3: stress clash in tautomorphemic environments

To extend the investigation of WRG's morpho-phonological deficit, Experiment 3 examined stress which offered another opportunity to examine the effects of phonological complexity in the context of morpheme assembly.

Languages tend to prefer that stressed syllables not occur too far or too near to one another, a preference that has been termed *eurhythmy*. As a consequence, syllables tend to appear in configurations of alternating stress, and stress on adjacent syllables (*stress clash*) is dispreferred in many languages including English (Hayes, 1984; Selkirk, 1984). As discussed in the Introduction, this dispreference can be observed in the fact that relatively few English monomorphemic words contain stress clash (Hammond, 1999) and even instances of stress clash across words may be repaired through stress-retraction (e.g., Tennesseé wómen → Ténnessee wómen, antíque cháir → ántique cháir; Liberman & Prince, 1977). Finally, although stress clash is permitted in compound words (e.g., *aírpòrt*, *políce càr*; compare *téacùp* to *híccup*) and words containing certain suffixes (e.g., *príesthòod*), a number of English suffixes will not combine with stems if the resulting word would contain stress clash (e.g., -*ize*: *rándom-ìze*, *shépherd-ìze* but **obscéne-ìze*, **corrúpt-ìze*; -*eer*: *moúntain-èer*, *éngine-èer*, *cámel-èer* but **balloón-èer*, *-*guitár-èer*, **giráffe-èer*; Raffelsiefen, 1996).

Derived nouns formed by adjective + ness were examined in Experiment 3 to determine if eurhythmy affected WRG's production of multi-morphemic words. Three types of stem adjectives were considered: (1) monosyllabic (*brísk*); (2) disysyllabic and iambic (primary stress on final syllable; *uníque*). (3) disyllabic and trochaic (primary stress on first syllable; *cléver*). When suffixed with -*ness*, monosyllabic and iambic adjectives result in stress clash (*brísknèss*, *uníquenèss*), unlike trochaic adjectives that do not contain stem-final stress (*clévernèss*).[3] WRG's ability

[3] Although the present discussion interprets WRG's errors as being related to stress clash, it is also possible that there may be a phonotactic preference for -*ness* to follow a disyllabic trochee rather than a disyllabic iamb, similar to the Homeric infix –*ma*- (sáxo-ma-phone, féuda-ma-lism, híppo-ma-potamus; Yu, 2004). Under this hypothesis, -*ness* may legally combine with any adjective but words containing stems that are disyllabic trochees would be more well-formed than words with stems of other metrical configurations. Interestingly, Yu (2004) claims that epenthetic repairs are permissible in Homeric infixation to improve dispreferred stress patterns (e.g., cáre-ma-ful → [kɛr<u>ə</u>məfəl], líve-ma-ly → [laɪv<u>ə</u>məli]). Regardless of whether WRG's epenthesis was in response to stress clash or a metrical selectional preference on the part of -*ness*, the interpretation is the same.

to produce -*ness*-suffixed nouns was tested in elicitation, reading, and repetition. Given the evidence from Experiment 1 of WRG's difficulty with marked or complex phonological sequences generated by morpheme combination, we would expect selective difficulties when -*ness* generates stress clash (with monosyllabic and iambic adjectives) compared to when there is no stress clash (with trochaic adjectives).

5.1. Method

The general procedures for the three production tasks were the same as in Experiment 1. For the elicitation task, the sentence frame used to elicit -*ness* suffixed forms was "It/This man is <adjective>. It/He shows signs of _____." (e.g., "This man is happy. He shows signs of _______"). In order to maximize lexical processing and actual morpheme assembly rather than simple repetition of the adjective stimulus and addition of -*ness*, we also included in the task adjectives that combine with -*ity* (e.g., "This man is sane. He shows signs of ______"). The suffix -*ity* also generates adjectival nominalizations in English as in divine → divinity and opaque → opacity. Since it is largely unpredictable whether an adjective combines with -*ity* or -*ness*, this morphological information is assumed to be learned and stored as a part of word's lexical representation. Furthermore, while nouns formed by -*ness* are strict combinations of the root and suffix, nouns formed by -*ity* contain a variety of phonological changes such as stress shift (rígid → rigídity), vowel change (sane → sanity), and velar softening (opaque → opacity; see Burzio, 2002). At least some of these phonological changes cannot be derived by rule and therefore must be listed (e.g., noble → nob[ɪ]lity but mortal → mort[æ]lity). Thus, by testing together nouns containing -*ity* and –*ness*, the chance of engaging morphological processing should be maximized (at least in elicitation).

In all production tasks, nouns taking -*ity* were randomly presented along with the two types of -*ness* suffixed nouns (clash and no-clash). In total, 428 words were tested in elicitation (134 clash, 80 no-clash, and 214 -*ity)*, 226 words in reading (83 clash, 65 no-clash, and 78 -*ity)* and 107 words in repetition (34 clash, 18 no-clash, and 55 -*ity*). The stress-clash nouns tested in each task included both monosyllabic adjectives + *ness* (*brísknèss*) and iambic adjectives + *ness* (*uníquenèss*).

5.2. Results and discussion

Here we report the results of items that take the -*ness* suffix; accuracy with -*ity* items was reported in the Case Description section and are not relevant for evaluating the effect of phonological complexity on WRG's performance. In terms of overall word accuracy for -*ness* items, WRG's elicitation responses were significantly less accurate with stress-clash compared no-clash nouns (43% vs. 64%; $\chi^2(1, N = 214) = 7.6$, $p < .01$) while WRG's reading responses showed a numerical trend in the same direction that failed to reach significance (31% vs. 40%; $\chi^2(1, N = 148) = 0.9$, $p > .05$). As in Experiment 1, WRG's performance in repetition was far better than in the other two tasks (only three errors were made). Repetition accuracy did not differ between stress-clash and no-clash nouns (91% vs. 100%; Fisher Exact Test $p = .3$).

Given the focus on stress clash, an analysis was performed in order to determine whether WRG's responses to derived words containing -*ness* revealed systematic changes to improve the stress pattern. For this analysis, minor phonological distortions that did not affect word stress (e.g., cleverness → [lɛvɝnɛs]) were ignored. Responses in which the stem was substantially distorted were excluded, as were perseverations. This resulted in the exclusion of 14 words from the elicitation task (seven in the clash condition and seven in the no-clash condition); no words were excluded from the reading or repetition tasks. WRG made three types of errors that improved the stress pattern of the target in the production tasks: (1) no-suffix errors (strángenèss → stránge), (2) wrong-suffix errors (rípenèss → rípeity; stérnnèss → stérnabìlity), and (3) post-stem insertions (ráshnèss → [rǽʃɪsnɛs]). The latter type of error always appeared between the stem and -*ness*. Examples of WRG's errors are shown in Table 2. Although one straightforward repair of stress clash would have been a stress shift (aloófnèss → áloofnèss), none of WRG's responses exhibited this pattern.

WRG's responses in elicitation and reading were similar (see Fig. 3). The results clearly reveal that, in both tasks, only post-stem insertions were strongly influenced by the stress pattern of the word. In elicitation, WRG made significantly more post-stem insertions in nouns with stress clash than in nouns with no-clash (32% vs. 0%, $\chi^2(1, N = 196) = 28.6$, $p < .0001$). This finding was replicated in reading (42% vs. 15%, $\chi^2(1, N = 142) = 12.2$, $p < .001$). The incidence of the other types of errors – no-suffix and wrong-suffix – did not differ between stress-clash and no-clash environments, neither in elicitation nor in reading (all Fisher's Exact Test *ps* > .19). As discussed above, WRG made only three errors on the -*ness* items but none of them affected the stress pattern of the target word. (smugness → [snʌgnɛs], sweetness → [svitnɛs], sternness → [stɝrnɛs]).

As in Experiment 1, since the adjective roots used as the stimuli had not been matched on length, frequency, and density, an analysis of stem accuracy was conducted. All perseverations were removed from the analysis and as before, only errors on the stem were considered. The results indicate that WRG's accuracy on stems did not differ in reading (clash: 60%, no-clash: 58%; $\chi^2(1, N = 144) = 0$, $p > .05$) elicitation (clash: 86%, no-clash 83%; $\chi^2(1, N = 204) = .36$, $p > .05$), or repetition indicating that the effect of stress on WRG's errors was truly related to the cross-morpheme stress environment and not to potential differences in WRG's ability to produce the stems.

As a second measure, a regression analysis was conducted to control for frequency, length, and neighborhood density (which had not been matched across the stress conditions) and to ensure that the pattern of performance in stress clash environments could not be reduced to the influence of sonority or coda complexity. Given WRG's demonstrated sensitivity to sonority in suffixed coda clusters, it is conceivable that WRG made insertion errors in Experiment 3 in order to improve coda structure, for example either by

Table 2
Representative coda errors made in Experiment 3.

Error type	Target	Response
Post-stem insertion	Briskness	[brɪskɪdnɛs]
	Ripeness	[raɪpɪdnɛs]
	Toughness	[tʌfɪsnɛs]
	Illness	[ɪlənɛs]
	Aloofness	[əlufɪsnɛs]
	Sedateness	[sədeɪtɪdnɛs]
	Awareness	[əwɛrɪdnɛs]
Wrong suffix	Foreignness	[fɔrɛnɪti]
	Nastiness	[næstɪti]
	Remoteness	[rimoʊtəbl]
No suffix	Evenness	[ivən]

simplifying clusters (briskness → [brɪs.kɪd.nɛs]) or by resyllabifying coda consonants into onset position (toughness → [tʌ.fis.nɛs]).

As in Experiment 1, a mixed-effects logistic model was created containing the log HAL frequency and phonological neighborhood density for each stem (values were obtained from the English Lexicon Project website, Balota et al., 2007). To evaluate effects of coda complexity, the number of segments in the stem coda (0–2) and the sonority of the final phoneme in the root (values: vowel/sonorant, obstruent) were added. Finally, the model also included a stress pattern variable (no-clash, clash). In addition to these fixed-effects variables, the model also contained random intercepts for each target word as well as random slopes for stress pattern. The number of segments in the stem coda and sonority of the stem-final phoneme were tested in separate models due to issues with model convergence. Model comparisons revealed that the number of coda segments in the stem did not significantly contribute to WRG's post-stem insertions ($\chi^2(1) = .009$, $p = .9$) and that the sonority of the final phoneme in the root only approached significance ($\beta = 0.40$; s.e. = 0.2; $z = 1.8$; $\chi^2(1) = 3.5$, $p = .06$).

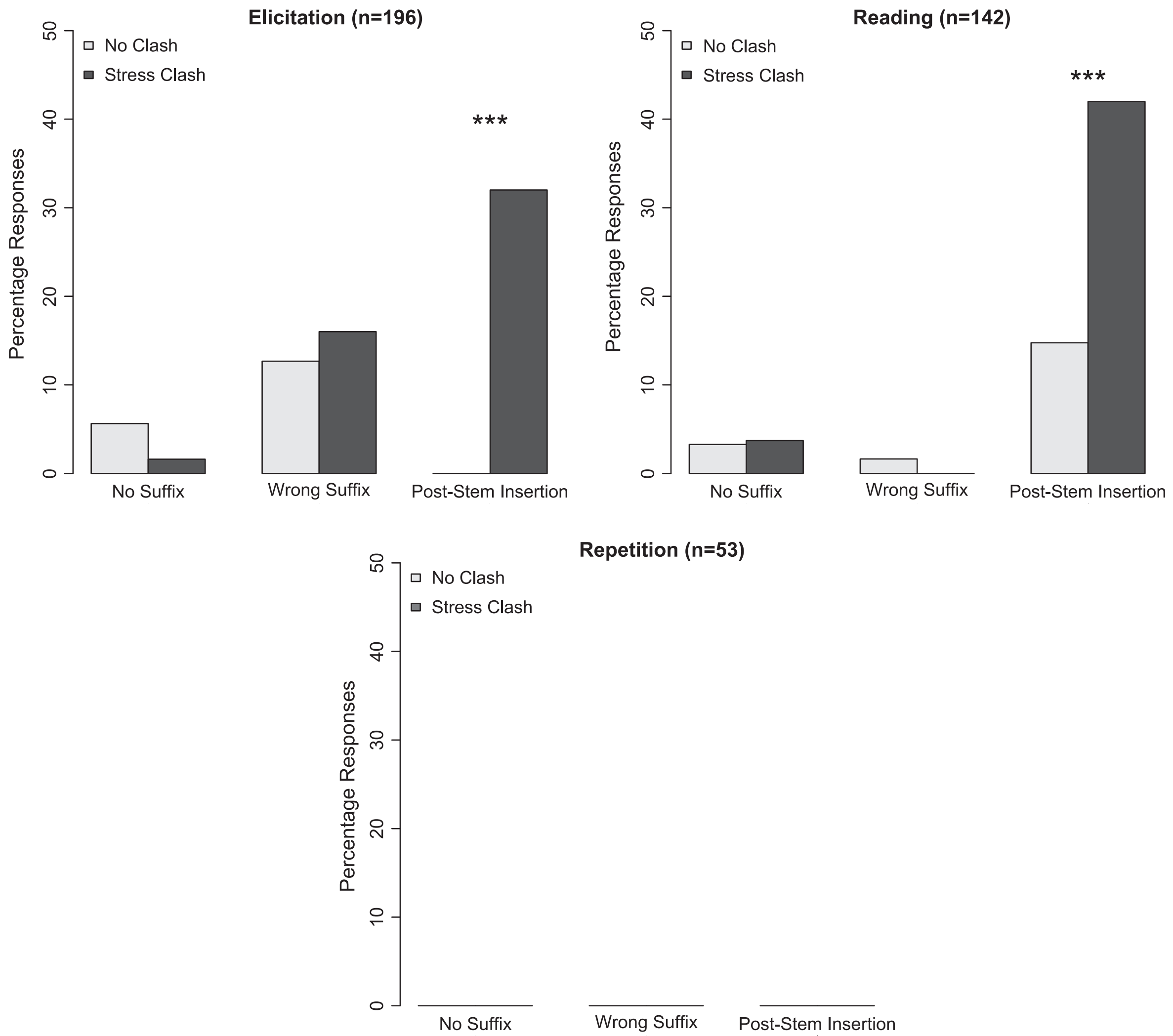

Fig. 3. WRG's stress-changing errors on adjectives suffixed with -ness containing stress clash (e.g., brísknèss, uníquenèss) and no stress clash (e.g., clévernèss). In both Elicitation and Reading, WRG made significantly more post-stem insertion errors on stress clash words than no clash words. ***$p < .001$.

Critically, however, stress pattern was significant in both the model containing root coda length (β = 3.96; s.e. = 1.59; z = 2.50; $\chi^2(1)$ = 23.8, $p < .001$) and the model containing root-final sonority (β = 3.77; s.e. = 1.64; z = 2.30; $\chi^2(1)$ = 22.0, $p < .001$), with post-stem insertions being more likely in cases of stress clash than in words without stress clash. This analysis indicates that WRG's insertion errors in Experiment 3 were primarily driven by the word's stress pattern independently of sonority effects, which contributed only marginally.

To summarize Experiment 3, in both elicitation and reading, WRG made significantly more post-stem insertion errors in words with stress clash than in words with no stress clash. The fact that all but 1 of these errors improved the word's stress pattern (eliminating stress clash) and that they were absent in repetition strongly suggests that they were phonological repairs produced by an impaired phonological grammar (the absence of errors in repetition indicates that post-lexical processes were relatively unimpaired).

5.3. Feature agreement in post-stem insertions

An interesting pattern emerges when the distribution of WRG's post-stem insertions of Experiment 3 is considered. These insertions always correspond to the incorrect addition (epenthesis) of a syllable. Across reading and elicitation, the inserted syllables took a variety of forms: [ɪd], [ɪs], [nɪs], [nɛs], [id], [i], and [ə], with the first two forms being the most common. When the epenthetic syllables are grouped by their final segment (either [d], [s], or a vowel), it becomes evident that they maintained the manner of the stem-final segment (see Table 3). Adjectives that end in a stop tended to take epenthetic [ɪd] (baldness → [baldɪdnɛs], compactness → [kəmpæktɪdnɛs], ripeness → [raɪpɪdnɛs]), adjectives ending in a fricative or affricate tended to take [ɪs] (richness → [rɪʧɪsnɛs], toughness → [tʌfɪsnɛs], rashness → [ræʃɪsnɛs]), and adjectives ending in a sonorant tended to take a bare vowel (thinness → [θɪninɛs], tenderness → [tɛndɝninɛs], illness → [ɪlənɛs]). It should be noted that WRG was not merely copying the stem-final consonant—he never produced forms such as ripeness → [raɪpɪpnɛs] or briskness → [brɪskɪknɛs]. The epenthetic consonant (when it appeared) was always [d] or [s], depending on the manner of the stem-final consonant (see Van Lancker, Bogen, and Canter (1983) for a related case of an aphasic individual whose suffix-like epenthetic errors agreed in voicing with the final consonant of the target). The systematic relationship between the manner of the stem-final consonant and epenthetic syllable bears a resemblance to consonant harmony systems in the world's languages that require consonants in words to agree in various features. These data thus provide further evidence that WRG's post-stem insertion errors originated from simplification mechanisms deployed by an intact phonological grammar.

6. General discussion

We have reported on an individual, WRG, who suffered from a severe disruption to the lexical (morpheme) levels of processing in the face of relatively well-preserved post-lexical phonological processing. We demonstrated that the deficit was not a classical morphological deficit as many of the errors were phonological and sensitive to phonological complexity, but also, that the deficit was not classically phonological, as the phonological errors were concentrated at morpheme boundaries. Experiment 1 documented that, when producing multi-morphemic words, WRG made insertion errors in syllable codas spanning morpheme boundaries that systematically improved the phonological well-formedness of the cross-morpheme environment (specifically, coda sonority). Along similar lines, Experiment 3 demonstrated that WRG made phonological repairs in heteromorphemic instances of stress clash, with clash-eliminating repairs occurring between the word's morphemes. In striking contrast with these findings, Experiment 2 established that WRG's errors in tautomorphemic codas were not sensitive to sonority, establishing a critical dependency between the phonological repairs and morphological structure.

Table 3
Distribution of epenthesized syllables as a function of the manner of the stem's final consonant.

Manner of stem-final consonant	Epenthesized syllable		
	[Vd][a]	[Vs]	[V]
Stop	34	5	1
Fricative/affricate	4	16	3
Sonorant	3	1	15

[a] V indicates vowel.

This pattern of performance is what one would expect from a morpho-phonological impairment: phonologically motivated errors in multimorphemic (but not monomorphemic) words, particularly at the junctions between morphemes. These findings have implications for our understanding of morphological, phonological, and morpho-phonological processing that will now be discussed.

6.1. Implications for morphological processing

In Experiments 1 and 3, WRG often made no-suffix and wrong-suffix errors. These morpheme-based errors occurred with equal frequency across the different phonological environments of morpheme junctions (SO/OO, clash/no-clash), indicating that they were uninfluenced by phonological well-formedness. These morpheme-based failures indicate that morphological selection takes place prior to and can be unaffected by constraints imposed by the phonological grammar.

In fact, a subset of WRG's productions from Experiment 3 provide further support for the distinction between morpheme-level selection and phonological processes. WRG was administered 347 adjectives that combine with *-ity*, e.g., *rigid/rigidity*, *sincere/sincerity*. On 32 occasions, WRG erroneously suffixed these stems with *-ness* (e.g., timidity → timidness, sanity → saneness) allowing us to observe the effect of stress in these novel forms. Of these 32 trials, 19 resulted in stress clash when suffixed with *-ness* (e.g., *sáne*, *opáque*, *inténse*, *verbóse*) while 13 did not (e.g., *fértile*, *tímid*, *supérior*). Note that the target responses for these items involved the *-ity* suffix and did not contain stress clash, while the errors that WRG produced by suffixing the words with *-ness* often did. This means that in 19/32 (59%) of the cases, WRG's morphological errors actually *decreased* the phonological well-formedness of the words. This indicates that morphological processes operate with some degree of independence from phonological processes; if they were more tightly connected, we would expect morphological errors to result in improvements in phonological well-formedness. Further, on 12 of the 19 responses in which stress clash was introduced, WRG made stress-changing phonological insertion errors (e.g., chastity → [ʧeɪstɪsnɛs], obesity → [oʊbisɪsnɛs], verbosity → [vɝbosɪdnɛs]), but he never made the analogous error in the no-clash responses (two-tailed Fisher's Exact Test: $p = .0004$). These errors illustrate two distinct operations at work: (1) impaired morphological processes erroneously selected *-ness* for production and (2) intact phonological processes, acting on these representations, repaired the metrical structure through epenthesis. These findings thus support the claim made by theories of spoken production that morphological selection generally occurs at a relatively early stage of processing before detailed phonological representations are computed.

This characterization does not exclude the possibility that there are conditions in which phonological features affect morphological selection, creating circumstances under which the interplay between phonology and morphology may be considerable. The English comparative and superlative is one such example; the decision to use the suffix *-er/-est* (e.g., smarter, *more smart) or the analytic construction *more/most* (more intelligent, *intelligenter) depends on the number of syllables of the root and the C/V status of its final phoneme. The mechanisms that allow phonological features to determine the selection of specific morphological forms are currently unclear. However, WRG's case indicates that in many cases, morphological selection is largely impermeable to phonology.

6.2. Morpho-phonological processing

WRG's pattern of performance clearly fits the profile of a morpho-phonological impairment and appears to be the first case of its kind to be documented. Two questions remain: what was the most likely functional impairment that led to WRG's pattern of performance and what does this reveal about the cognitive processes that support intact word production? We now consider each of these questions in turn.

As discussed in the Introduction, a morpho-phonological impairment could likely arise from one of two complementary damage profiles: impaired lexical processes sending poorly assembled multimorphemic phonological representations to intact post-lexical processes or an impaired post-lexical multimorphemic 'module' acting upon properly assembled multimorphemic phonological representations. While this is necessarily speculative, we believe that the lexical damage hypothesis more parsimoniously accounts for WRG's errors. WRG's clear lexical impairment (as indicated, for example, by his poor performance in picture naming) may well have included those processes responsible for combining the phonological content of different morphemes. At the same time, his excellent general performance in repetition, coupled with the fact that he never made a post-stem insertion error in repetition, strongly argues against a post-lexical impairment. WRG's impairment may have caused segments from different morphemes to be more weakly related to each other than segments from the same morpheme. This weakness may have allowed the phonological grammar to optimize phonological well-formedness at exactly these junctures between morphemes.

This proposal connects with production data from neurologically intact individuals that highlights the pivotal function of morpheme assembly in multimorphemic words. Using articulatory measurements, Cho (2001) found that articulatory gestures within the same morpheme were more integrated with each other than articulatory gestures that spanned across morphemes. Cho argued that this could be accounted for using the notion of *bonding strength* that has been proposed in Articulatory Phonology framework (Browman & Goldstein, 2000). In Articulatory Phonology, articulatory gestures (such as the lip closure of a bilabial stop) are formalized as individual dynamical systems that must be coordinated (coupled) with each other through phase relations. Bonding strength is a real-valued parameter that specifies how tightly two gestures are coordinated in time. Thus, at articulatory planning levels, gestures may be more weakly bonded to each other when they are heteromorphemic than when they are tautomorphemic.

Accordingly, we propose that it may be possible to borrow the notion of bonding strength—informally for the time being—in order to describe the various relationships that exist between phonological representations at *segmental* levels in normal spoken production. In this conception, phonemes within the same morpheme have a high bonding strength, accounting for their cohesion as a lexical unit. This may be because they are stored together in long-term memory and/or are produced frequently as a unit. Phonemes in different morphemes, however, since they are assembled on the fly, are more weakly bonded to each other, resulting in weaker cross-boundary structural relationships.

In our proposal, phonemes are bonded to each other sufficiently strongly during the course of intact/unimpaired speech planning (even in heteromorphemic environments) to prevent the phonological grammar from modifying structures such as OO codas and instances of stress clash. As a result of his brain damage, WRG was unable to establish strong enough bonds between the phonemes of different morphemes, allowing the phonological grammar to express itself at morpheme boundaries. Phonemes within the same morpheme were robustly enough related to each other structurally to prevent the phonological grammar from acting within morphemes. This hypothesis, in addition to accounting for the differences between heteromorphemic and tautomorphemic clusters, would also explain why WRG did not make other types of repairs such as stem-final deletion and stress shift. These changes would have required morpheme-internal modifications

Table 4
Kia Rondo neologisms containing the suffix -ness.

Kia Rondo neologism	Stress adjacent to -*ness*?	Epenthesis?
Horsepowerness	No	No
Lookscanbedecievingness	No	No
Stability all-overness	No	No
Seven-ness	No	No
Cup-holderness	No	No
Console multipurposeness	No	No
Superior performanceness	No	No
Environmental protectionness	No	No
Airbag excessiveness	No	No
Tire watchfulness	No	No
Giddyupidness	Yes	Yes
Anti-whiplashiness	Yes	Yes
Stoponadimeyness	Yes	Yes

and were likely to be blocked by the strong inter-morpheme structural relationships posited to exist within stored lexical items.

This proposal, adapted from Cho's (2001) findings and extended to the segmental level, predicts that bonding strength differences exist between tauto- and heteromorphemic environments, even in neurologically intact individuals. While anecdotal, a recent advertising campaign may provide supporting evidence for this claim. Specifically, in a series of advertisements that appeared in print and television ads as well as on the internet, Kia Motors introduced a set of words it called "Rondoisms" to promote its vehicle, the Kia Rondo. With ads featuring rainbows, music from the musical *Hair*, and words like *huge cabinosity*, *safety all-overness*, *precision steerology*, and *seat folding effortlessness*, the campaign attempted to associate a certain 60's-inspired nirvana with the Rondo.

One of the ads introduced the term *giddyupidness*, which bears a striking resemblance to WRG's responses ("Dude", 2007).[4] There does not appear to be any particular reason based on the content of the ad that the neologism (consisting of *giddy-up* and *-ness*) should contain [ɪd]. An inspection of the Rondoisms website suggested, however, that like WRG, the inserted material had its origin in phonological well-formedness. Of the more than 16 neologisms created for the campaign, only two other words contained phonological material not present in either the stem or the suffix: *antiwhiplashiness* and *stoponadimeyness* (Kia Motors, 2007).[5] The neologisms ending in the suffix *-ness* are presented in Table 4.

It is intriguing that all three instances of epenthesis (*giddyup*, *whiplash*, and *stoponadime*) involve stress clash. Of the words suffixed with *-ness*, only the three containing stress clash contained inserted material. It seems reasonable that the creators of the advertisement could have been tacitly aware of the stress clash (perhaps performing their own wordlikeness judgments) and inserted the syllables in order to make the words sound more appealing to customers. This example thus provides at least some evidence that neurologically intact speakers are sensitive to and repair heteromorphemic cases of stress clash at morpheme boundaries.

6.3. Implications for localizing deficits

In addition to shedding light on the interface between morphological and phonological processing, WRG's case illustrates the fact that error type and damage locus are not transparently related to each other. Although WRG makes 'phonological' errors, comparison of his performance across tasks indicates that his phonological processing is intact. Given the specific pattern of performance (impaired lexical processing, phonologically-sensitive errors in multimorphemic but not monomorphemic words, spared repetition) the most parsimonious account is one in which WRG's phonological grammar functioned appropriately but generated errors given damage elsewhere (earlier) in processing. Thus, difficulty at one level of processing can create errors that resemble those that arise from damage at other levels. This report thus underscores the importance of considering evidence from different sources (specifically, error types and task comparisons) and, in doing so, provides a guide for disentangling lexical, morphological and phonological influences in naming deficits, not only in English, but also in other languages with different morpho-phonological characteristics.

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[4] Many thanks are due to Christina Warner for bringing this to our attention.

[5] One other word, *cabinocity*, contains extraneous segmental material. This word appears to have been formed on direct analogy with words such as *curiosity* and *luminosity* (e.g., cabin-ous-ity).

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