AUTHOR QUERY FORM

ELSEVIER	**Journal:** CORTEX **Article Number:** 439	**Please e-mail or fax your responses and any corrections to:** **E-mail:** **corrections.esnl@elsevier.tnq.co.in.** **Fax: +31 2048 52789**

Dear Author,

Any queries or remarks that have arisen during the processing of your manuscript are listed below and highlighted by flags in the proof. Please check your proof carefully and mark all corrections at the appropriate place in the proof (e.g., by using on-screen annotation in the PDF file) or compile them in a separate list.

For correction or revision of any artwork, please consult http://www.elsevier.com/artworkinstructions.

Articles in Special Issues: Please ensure that the words 'this issue' are added (in the list and text) to any references to other articles in this Special Issue.

Uncited references: References that occur in the reference list but not in the text – please position each reference in the text or delete it from the list.	
Missing references: References listed below were noted in the text but are missing from the reference list – please make the list complete or remove the references from the text.	
Location in article	**Query / remark** **Please insert your reply or correction at the corresponding line in the proof**
Q1	Please check the affiliation ''a''.
Q2	Please note that the affiliation has been split as affiliations ''a'' and ''b''. Please check.
Q3	Please note that references ''Garret, 1980'', ''Roelofs, 1997a'', ''Kats, 1991'', ''Garcia-Orza and Leon-Carrion, 2005'', ''Barcellona corpus (1988)'', ''Glasspoool et al., 2006'', ''Burgess and Hitch, 1999'' have been changed to ''Garrett, 1980'', ''Roelofs, 1997'', ''Katz, 1991'', ''Garcia-Orza and León-Carrión, 2005'', ''Barcellona corpus (1989)'', ''Glasspool et al., 2006'', ''''Burgess and Hitch, 1992'' respectively, so that these citations matches the reference list. Please check.
Q4	Please check the hierarchy of the headings and sub-headings.
Q5	Please provide the expansion for the term ''STM'', ''ISR'', ''CVA'', ''SD'', ''n.s.'', if necessary.
Q6	Please note that references ''Shallice et al. (2002)'', ''Caramazza and Miceli, 1990'', ''Gupta, 1996'', ''Gupta and MacWhinney, 1997'', ''Brown et al., 2000'', ''Romani et al., submitted for publication'', ''Galluzzi and Romani, in preparation'', ''Romani and Galluzzi, submitted for publication'' are cited in the text but not provided in the reference list. Please provide them in the reference list or delete citations from the text.
Q7	Please check the year of publication for reference ''Caramazza et al., 1987''.

Q8	Please note that references ‘‘Baddeley (1990)’’, ‘‘Dell, 1986’’, ‘‘Shallice and Warrington, 1977’’, ‘‘Ward et al., 1998’’, ‘‘Wheeldon and Levelt, 1995’’, ‘‘Wheeldon and Morgan, 2002’’ are not cited in the text. Please cite them in the text or delete from the reference list.
Q9	Please note that reference ‘‘Dell et al., 1997’’ was changed to ‘‘Dell et al., 1997a’’, ‘‘Dell et al., 1997b’’ both in the citation and in the reference list. Please check.
Q10	Please check the author name ‘‘Granà A’’ in reference ‘‘Romani et al., 2002’’.
Q11	Please note that references ‘‘Ward and Romani, 1998a’’, ‘‘Ward et al., 1998b’’ was changed to ‘‘Ward and Romani, 1998’’, ‘‘Ward et al., 1998’’ in the reference list. Please check.
Q12	Please check the layout of ‘‘Table 6’’ and Table in Appendix A.

Electronic file usage

Sometimes we are unable to process the electronic file of your article and/or artwork. If this is the case, we have proceeded by:

☐ Scanning (parts of) your article ☐ Rekeying (parts of) your article ☐ Scanning the artwork

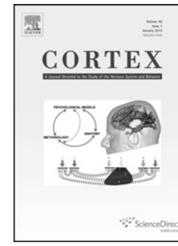
Thank you for your assistance.

cortex xxx (2010) 1–19

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/cortex



Research report

Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors

Cristina Romani [a,b,*], *Claudia Galluzzi* [a,b] and *Andrew Olson* [a,b]

Q1 [a] *University of Birmingham, Fondazione Santa Lucia, Rome, Italy*
Q2 [b] *Aston University, Birmingham, UK*

ARTICLE INFO

Article history:
Received 1 July 2008
Reviewed 16 October 2008
Revised 19 January 2009
Accepted 29 October 2009
Action editor Dr Myrna Schwartz
Published online xxx

Keywords:
Aphasia
Phonological output buffer
Phonological errors
Buffer impairment
Length effects
Positional effects

ABSTRACT

Single word production requires that phoneme activation is maintained while articulatory conversion is taking place. Word serial recall, connected speech and non-word production (repetition and spelling) are all assumed to involve a *phonological output buffer*. A crucial question is whether the same memory resources are also involved in single word production. We investigate this question by assessing length and positional effects in the single word repetition and reading of six aphasic patients. We expect a damaged buffer to result in error rates per phoneme which increase with word length and in position effects. Although our patients had trouble with phoneme activation (they made mainly errors of phoneme selection), they did not show the effects expected from a buffer impairment. These results show that phoneme activation cannot be automatically equated with a buffer. We hypothesize that the phonemes of existing words are kept active though permanent links to the word node. Thus, the sustained activation needed for their articulation will come from the lexicon and will have different characteristics from the activation needed for the short-term retention of an unbound set of units. We conclude that there is no need and no evidence for a phonological buffer in single word production.

Several models of speech production include a phonological output buffer which, in connected speech, would hold on to phonological representations while these are converted into the corresponding articulatory programs (e.g., Fromkin, 1973; Dell et al., 1997a; Ellis, 1980; Shattuck-Hufnagel, 1979; Q3 Garrett, 1980). Empirical studies using aphasic patients have shown that a phonological output buffer is also used to produce non-words (Bub et al., 1987; Bisiacchi et al., 1989; Caramazza et al., 1986), but the evidence that a buffer is involved in single *word* production is more equivocal (see Shallice et al., 2000).

Studies with unimpaired speakers have provided some evidence that a buffer is needed in word production. For example, it has been shown that speech onset times are affected by the length of the word to be produced (Santiago et al., 2000, 2002; Roelofs, 2002a; Meyer et al., 2003) and by priming both the first and second syllable of disyllabic words (Meyer, 1990; Meyer and Schriefers, 1991; Schriefers and Teruel, 1999). These results show that speech is not initiated before a stretch of the phonological representation has been planned. However, the buffered representations responsible for these effects may be articulatory rather than phonological.

* *Corresponding author*. School of Life and Health Sciences, Aston University, Aston Triangle, Birmingham B4 7ET, England, UK.
E-mail address: C.Romani@Aston.ac.uk (C. Romani).
0010-9452/$ – see front matter © 2010 Elsevier Srl. All rights reserved.
doi:10.1016/j.cortex.2009.11.004

The purpose of our study is to gather evidence for the involvement of a buffer in word production by assessing whether the same capacity limitation which characterizes temporary retention also characterizes single word production tasks. We will index capacity limitations with length and positional effects and we will examine whether these effects are present in the phonological errors made in single word repetition and reading by aphasic patients. To ensure that the level tapped is phonological rather than articulatory we will consider only patients with no articulatory difficulties.

In this Introduction, we will first briefly discuss reasons why a phonological buffer should or should not be implicated in word production. Secondly, we will outline the type of evidence that can be used to bear on this question (length and positional effects). Thirdly, we will review evidence from the existing literature and finally, we will outline the plan of our study.

1. Why a phonological buffer in word production?

Some form of sustained activation is needed during word production. Even if phonemes are activated in parallel in lexical access, some further processing stages are likely to be carried out ***serially*** and this will require sustained activation. Both syllabification processes and processes of phonological-to-articulatory conversion are likely to occur serially.

In Levelt, Roelof and Meyer's model (1999; henceforth LRM), phonemes are activated in parallel from lexical nodes (the term *selected* is also used, e.g., Roelofs, 1997, p. 258) and, then, syllabified on the fly by a serial process that works from the beginning to the end of the word and assigns syllable positions to each of the phonemes. Not all production models, however, include on-line syllabication. Syllable structure can also be stored in the lexicon and, thus, retrieved in parallel together with the linear sequence of phonemes (e.g., see Romani et al., submitted for publication). Articulatory representations, however, are much *less* likely to be stored. The reason to have articulatory representations distinct from phonological representations is adaptation to context and this includes not only the phonological context within the word, but also the prosodic context within the utterance and this cannot be stored. Moreover, phoneme-to-articulatory is likely to occur serially. Speech takes place in time and ultimately commands to the articulators must be dispatched in a temporal sequence. Thus, an articulatory planning stage – intermediate between phonological representations and motor implementation (e.g., Romani et al., 2002; Romani and Galluzzi, 2005) – is likely to operate with a degree of *seriality* to focus resources on the phonemes that are to be produced first.

Any serial processing stage will require *sustained* activation of the phonemes on which the operations are carried out. The question, however, is whether this activation is the same as that that the literature characterizes with the expression '*phonological buffer*' or whether, instead, comes from the lexicon. For example, the LRM model just mentioned does not include a phonological buffer in single word production. LR&M do not say this explicitly, but since phonemes are activated by lexical nodes, there is no need for further STM resources. Instead, they hypothesize the existence of an articulatory buffer. The syllabified segments access a library of syllable-sized articulatory programs which accumulate in this buffer until a complete phonological word is ready for articulation (Roelofs, 2002b, p. 466). A buffer is needed here since there is no higher-level node providing activation to the ordered set of articulatory syllables. The model by LRM, then, well exemplifies a model where a phonological buffer is not needed for word production given the existence of phonological lexical representations.

Other models, however, have assumed that a phonological buffer is needed even in single word production. A whole class of models has been developed to explain sustained phoneme activation during serial articulatory planning and/or motor implementation through activation gradients imposed on the phonemes or letters (Houghton, 1990; Hartley and Houghton, 1996; Glasspool and Houghton, 2005). Phoneme activation would be higher for the beginning phonemes and decrease progressively so that phonemes become available to the articulators in the right order. In these models, activation gradients have been described as having the function of a buffer, but this characterization has not gone unchallenged. Other authors have assumed that activation gradients are a property of lexical access rather than a distinct function involved in prolonging lexical activation (e.g., Ward and Romani, 1998, 2000; Glasspool et al., 2006; see also discussion later).

The question of whether the sustained activation needed in single word production is the extra boost that we equate with the buffer or it is indistinguishable from the activation needed in lexical access is not just terminological, but it has theoretical and empirical consequences. It is linked to the more general question of whether the resources involved in temporary retention are the same as those involved in representing information long term. If they are the same, than, the same effects of capacity limitations which characterize short-term retention should also apply to the access of '*permanently*' stored information. In other words, they should also characterize tasks tapping lexical access such as repetition and reading when performance is strained as it is the case in patients making phoneme-selection errors in word production (for the view that there is only one kind of phonological activation see Martin and Saffran, 1997; Jefferies et al., 2006; Page et al., 2007; for the view of differences in representation and retention see Martin and Breedin, 1992; Oakhill and Kyle, 2000; Romani et al., 2008). We will consider length and positional effects – which are pervasive in the ISR literature – to be prima-facie evidence of capacity limitations.

2. Evidence of capacity limitations

2.1. Length

ISR is dramatically affected by the number of units in the series to recall, whether these units are letters, words or digits. It is also affected, however, by the length of the units. Longer words are recalled worse than shorter words. This is known as the *word length effect* and although is was, for some time, attributed to rehearsal (longer words take longer to be

Please cite this article in press as: Romani C, et al., Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors, Cortex (2010), doi:10.1016/j.cortex.2009.11.004

pronounced and, therefore, longer to rehearse), a consistent body of evidence now shows that it should be mainly attributed to longer words occupying more buffer capacity. What is important is the number of phonemes in a word and not how long it takes to pronounce it (e.g., Service, 1998). Consistently, the word length effect does not disappear in conditions which prevent rehearsal. Length effects are still present with non-words in articulatory suppression conditions (Romani et al., 2005) and with words in fast presentations rate conditions (Campoy, 2008). Both these conditions make rehearsal very difficult. Therefore, finding length effects in these conditions support the view that length effects are a crucial indicator of capacity limitations and not just linked to rehearsal.

If lexical activation is capacity limited as ISR, single word production should show length effects similar to those present in ISR and non-word repetition. Lexical activation may depend on word frequency and grammatical class. However, if activation is capacity limited, it will have to spread out among more units in the case of longer words. This will mean that phonemes belonging to a longer word will receive proportionally less activation. This is, for example, a feature of the activation gradient in Glasspool and Houghton's (2005) spelling model and contributes to the word length effects produced by the lesioned version of the model. Alternatively, if the activation used in short-term retention and in lexical access are different, then, the amount of activation a word node sends out may not be limited, but proportional to the number of phonemes. This hypothesis predicts that, although length effects may be indirectly caused by positional effects (longer words have more late positions), error rates on a given position should be the same for words of different lengths (see the Experimental Investigation for a more complete discussion of this point).

2.2. Positional effects

Short-term recall of phonological representations – whether they are series of words, series of non-words or single non-words – is strongly associated with a bow-shaped serial position curve (see Gupta et al., 2005; Romani et al., 2008). Serial position effects have been extensively assessed in patients with orthographic impairments.[1] The majority of cases have shown bow-shaped positional effects (for a symmetrical bow-shaped curve see: Caramazza et al., 1987; Posteraro et al., 1988; Trojano and Chiacchio, 1994; for a right-skewed bow-shaped curve see Aliminosa et al., 1993; De Partz, 1995; Jonsdottir et al., 1996). Competitive queuing models also show a bow-shaped serial position function when noise is added to the queue which is assumed to have the function of a buffer (e.g., Glasspool and Houghton, 2005). Other patients, however, have shown *linearly increasing error functions* and these have been given different interpretations. Some accounts have hypothesized that, the activation supplied by lexical representations to the phonemes follows an activation gradient to help with maintenance of phoneme order. The linear error functions seen in the patients, therefore, will be caused by a reduction in *lexical activation* (e.g., Ward and Romani, 1998; Cipollotti et al., 2004; Glasspool et al., 2006). Other accounts, however, have attributed these linear functions to buffer impairment. Phonemes at the end of the word spend more time in the buffer and, therefore, will be subject to more decay (e.g., Katz, 1991; Schiller et al., 2001). What is important, for the moment, is that capacity limitations clearly predict positional effects. Typically, bow-shaped serial position effects have been associated with a memory function. However, position effects could be linearly increasing if decay rather than interference is the crucial factor affecting later positions.

With this theoretical framework in mind we will now examine existing evidence for the involvement of a phonological buffer in word production.

3. Evidence for a phonological buffer in production

That a phonological output buffer is needed in connected speech is uncontroversial. To convey the right meaning, the duration, intonation and stress assigned to words must be adjusted according to the values of surrounding words (e.g., compare: '*THAT cat caught my bird*' and '*That cat caught my BIRD*'). Similarly, re-syllabifications across boundaries require several words to be simultaneously available (e.g., slip away → sli.pa.way). Speech errors which span word boundaries demonstrated that this is the case (e.g., ''The *d*oat is at the *d*ock''; Fromkin, 1973; Berg, 2005) and since the errors accommodate to their new phonological context, the buffered representations must be phonological rather than articulatory.

An output buffer, is also likely to be involved in ISR. There is evidence of selective impairments to a phonological output buffer (as opposed to an input buffer) affecting ISR of word lists (Romani, 1992; Howard and Franklin, 1993; Nickels et al., 1997; Martin et al., 1999; Howard and Nickels, 2005; Jacquemot and Scott, 2006) and recent evidence suggests that the same output buffer is used in ISR and connected speech. Similar errors made in ISR and spontaneous speech (Ellis, 1980) and in ISR and paced reading of word lists (Page et al., 2007). Finally, similar serial position curves are obtained when positions correspond to words, in ISR, or to individual phonemes, in non-word repetition (Gupta, 2005; Gupta et al., 2005; Archibald and Gathercole, 2007). These results link together connected speech, ISR and non-word repetition. What is lacking is evidence that phonological buffer is involved in single word production. The neuropsychological literature so far as only provided weak evidence.

3.1. Production of single words and non-words

In their seminal paper, Caramazza et al. (1986) described a patient, IGR, with poor digit span (3 items) and list recall, but with mostly fluent speech and very good repetition and reading of single words. IGR, instead, made phonological errors when repeating, reading and spelling single *non-words*. Here, the majority of errors were segmental (did not result in

[1] They have not been assessed in patients with a *phonological* buffer impairment, with the exception of LT who was reported to make more errors on the second syllable of bi-syllabic words and non-words (Shallice et al., 2000).

real words) and consisted of individual phoneme substitutions, deletions, insertions or transpositions. The similarity of errors across tasks was used to argue for damage to a single component corresponding to a phonological output buffer. This buffer would retain phonological representations before they were converted into articulatory representations (in the case of repetition and reading) or allographic representations (in the case of spelling).

Caramazza et al. (1986) drew a connection between a short-term store and effects of length and serial position. This connection was strengthened by the report of another patient, LB, who made errors that resembled those of IGR, but this time in spelling (Caramazza et al., 1987). There was a long list of similarities between the two patients: The majority of errors were segmental changes resulting in non-words; the most common type of error was a substitution and the least common was a transposition; among the substitutions, consonants were substituted for consonants and vowels for vowels; both patients showed length effects. Therefore, the two patients were assumed to have damaged analogous buffer components in the phonological and orthographic domain. Serial position effects, which were more systematically investigated in LB, showed a bow-shaped function with more errors in the middle than at either the beginnings or ends of words. This function was explicitly associated with a deficit to a memory component and with Wing and Baddeley's (1980) assumption that items in the middle of a series are subject to more interference.

There was also, however, an important difference between IGR and LB. LB and other dysgraphic patients studied subsequently were impaired at spelling *both* words and non-words (although words were less severely affected; see summary in Sage and Ellis, 2004). Instead, IGR and further patients with damage attributed to a phonological output buffer were impaired *only* with non-words (see English patient MV, Bub et al., 1987; Italian patient RR, Bisiacchi et al., 1989; and Spanish patient CSR, Garcia-Orza and León-Carrión, 2005).

Caramazza et al. (1987) argued that an orthographic buffer is used for both words and non-words because both kinds of stimuli require that orthographic representations are kept in memory while being converted, one by one, into allographic patterns. Spoken words may avoid serial conversion by accessing pre-packaged articulatory representations. The hypothesis of articulatory lexical representations is problematic, as already mentioned, but preserved performance with words may also be explained by assuming that information can be refreshed (or redintegrated) using stored phonological representations (see Bub et al., 1987; Bisiacchi et al., 1989; Hanley et al., 2002; for studies of ISR with control participants, see also Hulme et al., 1995, 1997). If words benefit from a different (lexical) activation than non-words, then, an impaired buffer may have no impact on word production or it may have an impact only when the buffer deficit is very Q6 severe. Shallice et al. (2002) opted for the second possibility. They described an Italian patient, LT, who shared a number of characteristics with the other patients with alleged buffer impairments, but who had difficulties with *both* words and non-words. Since LT was more severely impaired, Shallice et al. argued that previous patients were unimpaired on words only because of milder deficits.

Shallice et al.'s (2000) interpretation implies that all phonological segmental errors – whether they occur in producing sentences, words or non-words – can be attributed to a reduction in activation that they equate with a buffer function (see Buchwald and Rapp, 2006 for a similar interpretation of orthographic segmental errors). If this hypothesis is correct, however, similar limitation of capacity will characterize performance across tasks tapping STM (like recall of series of words or repetition single non-words) and tasks tapping lexical access such as repetition and reading of single words. Alternatively, phonological errors could stem a weakening of the connections between a word lexical unit and its associated phonemes (see Dell et al., 1997a, 1997b; Foygel and Dell, 2000) even in patients with no problems with sustained activation. This is investigated by our study.

4. Plan of study

Our study will address two related questions. The first is whether lexical activation is the same or different from a buffer function. If it is the same, then, we should find evidence of capacity limitations in the errors of *all* patients with a phonological impairment. Error rates per phoneme should increase with word length and there should be either bow shaped or linearly increasing serial position effects. Moreover, these effects should occur whether words or non-words are the targets. Instead, if lexical activation is different, at least some patients should show no evidence of capacity limitations.

The second question depends on the first. Even if phoneme selection and short-term retention are *distinguishable processes* one may ask whether damage to the buffer ever limits word production. Finding even a single patient where the errors can be convincingly related to capacity limitations will provide positive evidence. However, lack of evidence will be more difficult to interpret since a new patient who shows the characteristics of capacity limitations could always be described at a later point. Keeping these limitations in mind, if no patient in our series shows evidence consistent with a buffer impairment, the most parsimonious (preliminary) explanation would be that the phonological errors made in word production are mainly selection errors and buffer limitation have no effect.

To address these questions, we will report results from a series of aphasic patients who make phonological errors in single word production but do not have articulatory difficulties. Our experimental investigation is subdivided into three parts. In the first section, we show that our patients make similar errors in reading and repetition and that the errors resemble those of previous patients reported to have phonological buffer impairments. In the second section, we assess whether the rate of error per phoneme increases with word length for any of our patients and we determine whether length effects are present after word frequency is taken into account. In the third section, we assess whether effects of length are associated with a particular form of serial position curve. Finally, we focus on the one patient who is the best candidate for a buffer impairment and contrast the patterns of errors he makes in word and non-word repetition.

Please cite this article in press as: Romani C, et al., Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors, Cortex (2010), doi:10.1016/j.cortex.2009.11.004

5. Experimental investigation

5.1. *Participants*

The speech of the four reported buffer patients previously described in the literature has been described as ''mostly fluent without articulatory or prosodic difficulty (occasionally there were pauses and false starts at word beginnings)'' (IGR), ''fluent without any articulatory disturbance'' (RR), ''hesitant and circumlocutory with verbal paraphasias and marked word finding difficulty'' (MV) and ''fluent, but paraphasic'' (LT). To match these characteristics, we selected patients who make phonological errors in speech production, who have good or only mildly impaired phonological discrimination and who have fluent speech without clear signs of articulatory difficulties.

We report six Italian aphasic patients (AC, GM, MC, MP, RM and TC) who were part of a larger group of thirteen patients studied by Romani and Galluzzi (2005). They were referred to us by the Speech Rehabilitation Unit at Fondazione Santa Lucia and, with one exception, they all suffered from a left CVA (GM – right parietal). In our original study, they were classified as 'phonological' rather than 'apraxic' because of their low rate of phonetic errors in single word repetition (phonetic errors are errors where a phoneme is produced in a slurred and/or imprecise way). Five patients made fewer than 1.8% phonetic errors in word repetition. One patient, MC, made 4.1% phonetic errors, but this rate was still much lower than the rate made by the patients classified as apraxic (range 12.3–24.0%). Similarly, the phonological patients spoke more slowly than controls, but were much less affected than the apraxic patients. The exception was, again, patient MC, who showed very slow production, with many false starts. These characteristics suggest a probable overlap of deficits in MC.

5.2. *Method*

We will compare performance in two tasks: repetition and reading of single words. Both require spoken production, but they rely on different inputs. Thus, similar performance across tasks can be taken to imply damage to an output component. Additional background neuropsychological assessment can be found in Romani and Galluzzi (2005).

The same words were given in the two tasks to facilitate comparisons ($N = 773$ for each task). They came from five controlled lists assessing effects of imageability, grammatical class, phonological length, and complexity. Lengths ranged from 4 to 13 phonemes and the average length was 7.4 phonemes ($SD = 2$). Average syllable length was 3 ($SD = .9$). Average word frequency was 85 ($SD = 257$, range 0–4440), corresponding to an average log frequency of 3 ($SD = 1.6$, range 0–8.4). On a concreteness scale from 0 to 2 with steps of .25 the average concreteness was .9 ($SD = .8$). In sum, the stimuli contained a large variety of words representative of the Italian language.

5.2.1. *Procedure*

All patients were individually tested by the second author in a quiet room at the clinic. Testing was carried out over several sessions, each lasting approximately 1 h. In the repetition task, the examiner said a word aloud and the patient had to repeat it in her own time. In the reading task, written words were presented, one at a time, on a piece of paper.

5.2.2. *Scoring*

Tasks were taped to allow rechecking. For scoring purposes, we used the first response given by the patients. False starts and fragments were considered errors, even if followed by a correct response. For the purpose of the following analyses, words that were articulated slowly, with effort, syllable by syllable or contained phonemes which were pronounced in an imprecise or slurred way but were clearly recognizable as the target were considered correct.

5.3. *General characteristics of the errors*

Leaving aside length and positional effects, the following characteristics have been shared by previously reported phonological buffer patients: 1) the majority of errors were non-lexical phonological errors. 2) Non-lexical errors, for the most part, involved single phoneme transformations. Substitutions were the most common error, and deletions, insertions and transpositions occurred more rarely (although at a rate higher than chance see Shallice et al., 2000). 3) Segmental errors were phonologically motivated. Among the substitutions, most errors involved consonants and there was substantial overlap between target and error in terms of distinctive features or manner of articulation. 4) Similar error patterns occurred in reading and repetition. We will now examine all of these characteristics in our patients.

5.3.1. *Type of errors*

For all our patients, the great majority of errors resulted in non-words in both repetition and reading. Percentages of non-word errors ranged between 67% and 92% in repetition and between 66% and 85% in reading. Table 1 shows a break-down of the different types of non-word errors made in the two tasks. They were classified into four categories:

1) *Individual errors*. These are errors that involve up to three individual phonemic transformations in a single word. By phonemic transformations, we mean errors where a single phoneme is substituted, deleted, inserted or transposed (e.g., one error: /sfortso/>/sportso/; two errors: /krot efisso/> /frot ifisso/; three errors: /settimana/>/nettiklana/).
2) *Sequence errors*. These are errors that involve two or more adjacent phonemes. Like individual errors, sequence errors may involve substitutions, deletions, insertions or transpositions of sequences (e.g., /klausola/>/klauso/; /esperyentsa/> /esteperyentsa/; /turbavano/>/turbavero/; /dimostrava/>/dimostrale/).
3) *Multiple errors*. These are errors with more complex phonemic transformations affecting more than three non-adjacent phonemes (e.g., /indossava/>/inkwostala/; /filosofia/> /filagosiera/; /t inismo/>/t ilennyo/).
4) *Fragments*. These are errors where only the beginning part of the word is produced (less than half) or an upward intonation indicates that production of the word has not been completed (e.g., /sovente/>/some/..; /pregyera>/

Please cite this article in press as: Romani C, et al., Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors, Cortex (2010), doi:10.1016/j.cortex.2009.11.004

Table 1 – Number and percentage of different kinds of non-word errors in repetition and reading.

		Individual phon. (1–3)		Multiple (>3)		Fragment		Sequence		Stress		Total
		N	%	N	%	N	%	N	%	N	%	N
AC	Rep	128	82	9	6	10	6	10	6	0	0	157
	Read	104	79	1	1	16	12	3	2	8	6	132
GM	Rep	120	85	4	3	10	7	8	6	0	0	142
	Read	152	63	30	12	48	20	9	4	2	1	241
MC	Rep	649	76	139	16	41	5	20	2	0	0	849
	Read	303	72	39	9	52	12	23	6	1	0	418
MP	Rep	118	74	20	13	7	4	14	9	0	0	159
	Read	57	60	5	5	12	13	4	4	17	18	95
RM	Rep	46	35	1	1	81	61	4	3	0	0	132
	Read	35	49	0	0	21	29	2	3	14	19	72
TC	Rep	105	61	4	2	41	24	23	13	0	0	173
	Read	57	39	1	1	77	53	1	1	9	6	145

pregre/...; /spada/>/spa/...). Fragments may be completely correct up until the end of the fragment or they may contain errors.

The great majority of the non-word errors made by our patients were individual phonemic transformations. RM and TC, however, also made a large proportion of fragment errors. All patients showed clear similarities between the error patterns in repetition and reading. The only difference between tasks is the presence of errors involving stress assignment in reading (e.g., AC: /férmano/> /fermáno/; RM:/ árgine/> /argíne/; TC: /t ivíle/> /t ívile/). These errors show the contribution of a sub-lexical route. The Italian orthography is very transparent. Stress, however, is a lexical property of words and reading non-lexically will result in stress errors.

5.3.2. *Severity of impairment*

Since Shallice et al. (2000) suggested that a buffer deficit will affect words, but only when it is severe enough, it is important to compare the severity of our patients to that of other patients from the literature. To do so, errors have been subdivided into single errors involving only one phoneme transformation per word, double errors (involving two non-adjacent transformations) and complex errors involving three or more non-adjacent transformations. In addition, errors were categorized as fragments, omissions and errors involving sequences of phonemes (two or more adjacent phonemes). Single errors contributed between 35% and 55% of the total in repetition and between 35% and 67% of the total in reading. The proportion of single versus more complex errors in previously reported buffer patients ranged from 44% to 95% in repetition (LT: 44%, IGR: 61%, MV: 69%, RR: 95%) and from 59% and 83% in reading (LT: 59%, MV: 71%, IGR: 83%, RR 83%). Clearly, there is overlap in the range of severity of our patients and previously reported buffer patients. More detailed results are presented in the Appendix A.

5.3.3. *Type of segmental errors*

Table 2 shows the relative proportion of substitutions, deletions, insertions and transpositions made by our patients and by patients with attributed buffer damage. Only errors where a single transformation was made were included to allow comparison with previously reported patients. Our patients compare very closely with previous patients. Most errors

Table 2 – Percentage of different types of segmental errors for our patients and patients with attributed buffer damaged from the literature (in italics). Only single errors (errors involving a single phoneme change per word) are included.

	Sub %	Del %	Inser %	Transp %
Word repetition				
AC	69	17	11	3
GM	82	9	4	6
MC	84	5	9	2
MP	84	12	4	0
RM	70	12	16	2
TC	81	9	9	1
Total	**79**	**10**	**9**	**2**
LT	*71*	*10*	*12*	*6*
Non-word repetition				
IGR	*81*	*3*	*11*	*5*
MV	*80*	*12*	*8*	*0*
RR	*80*	*13*	*0*	*7*
LT	*75*	*7*	*8*	*9*
Word reading				
AC	88	5	2	5
GM	78	8	7	7
MC	80	5	11	4
MP	77	8	15	0
RM	79	8	11	3
TC	92	3	3	1
Total	**83**	**6**	**8**	**4**
LT	*88*	*5*	*4*	*1*
Non-word reading				
IGR	*81*	*6*	*13*	*0*
MV	*62*	*23*	*12*	*3*
RR	*74*	*21*	*6*	*0*
LT	*79*	*10*	*7*	*4*

Please cite this article in press as: Romani C, et al., Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors, Cortex (2010), doi:10.1016/j.cortex.2009.11.004

involve substitutions, with many fewer errors in the other categories. In most patients, the category with fewest errors is transpositions.

5.3.4. *Phonological similarity in the substitution errors*

The substitutions made by our patients are the focus of a separate paper (Galluzzi and Romani, in preparation), and here we only summarize relevant data. A selective impairment of either consonants or vowels can be taken as an indication that errors are phonologically motivated. Previous patients IGR and LT made a majority of substitutions on consonants, although the proportion was much lower in LT (for repetition, IGR: 81%; LT: 62%; for reading, IGR: 81%; LT: 57%). As a group, our patients made more errors on consonants, but there was substantial variation. Rates ranged from 49% to 99% in repetition and from 29% to 88% in reading. TC and MP made more vowel substitutions. What is perhaps more important (as also argued by Shallice et al., 2000), is that each patient showed a close correspondence between error types across tasks.

All our patients made consonant substitutions that preserved manner of articulation and shared distinctive features. Consistency in manner of articulation was assessed by categorizing target phonemes and errors into one of five classes: affricates, fricatives, liquids, nasals and obstruents. Errors stayed within class in 59% and 55% of substitutions in repetition and reading, respectively. The average number of distinctive features changed by a substitution was 3.4 in repetition and 2.8 in reading. These values are significantly lower than chance values (4.4 and 4.5) estimated using corpora of pseudo substitutions obtained by randomly recombining targets and error phonemes 1000 times.

5.3.5. *Discussion*

Our patients covered a range of severity, but, like LT (Shallice et al., 2000), they were toward the severe end of the spectrum. Like previously reported patients, they made mostly non-word errors and the transformations were mostly individual phoneme substitutions which were related to the target by manner of articulation, and involved a small number of feature changes. The same patterns were found in repetition and reading. In the following section, we will show that in the majority of patients, performance was significantly affected by word frequency.

It is clear that the errors made by our patients on words share a number of characteristics with the errors made by previous buffer patients on either non-words (IGR, RR, and MV) or both non-words and words (LT). However, by themselves, these characteristics are not enough to identify a buffer impairment since they could also be produced by impairments affecting the selection rather than short-term retention of phonemes. We will now examine whether length and positional effects can better discriminate between deficits of selection and deficits of temporary storage.

5.4. *Effects of length and frequency*

The strongest prediction made by the hypothesis of a buffer impairment is that word length should affect performance. Retaining more units (phonemes) should stretch the capacity of the buffer and result in more errors. Note, however, that the length effects predicted by a buffer impairment are more specific than those commonly reported in the literature. A buffer deficit predicts that error rates ***per phoneme*** will be higher for longer words, what we will call a *by-phoneme* length effect. The number of errors should *not* remain proportional to the number of phonemes in a word, but should increase disproportionally with word length, reflecting capacity limits. Instead, any phonological impairment will produce what we have called *a by-word* length effect, that is, fewer completely correct responses on longer words. This is because longer words simply offer more opportunity for errors, even if error probably per phoneme is constant (see, for example, Nickels and Howard, 1995, 2004; Ziegler, 2005; Olson et al., 2007).

Although length effects have been considered one of the principle hallmarks of a buffer impairment, they have been analyzed only by word and even these results have not always been strong and consistent across tasks. LT (Shallice et al., 2000) showed significant length effects in non-word repetition and word repetition and reading. IGR (Caramazza et al., 1986) showed a significant length effect in repetition, but not in reading. Bub et al. (1987) did not assess length effects in their patient, MV, and Bisiacchi et al. (1989) reported no significant length effect for their patient, RR.

Frequency effects, but not concreteness effects, have also been shown by some alleged buffer patients. IGR, LT, and MV all showed frequency effects (for MV frequency was only assessed in reading). Non-significant differences were reported for RR, but this could have been the result of ceiling effects. The influence of frequency is not surprising, whether phonological errors result from a selection impairment or a reduced buffer. More familiar/frequent words will have both more activation to guarantee phoneme selection and more activation to better support buffered representations. Concreteness effects may be seen more rarely because semantic representations are one step further removed from the phoneme level.

In our analyses, we will assess frequency and length effects first by word and then by phoneme.

5.4.1. *Frequency and length by word*

Table 3 shows performance for words of high and low frequency ranging from two to four syllables. For high frequency words, frequency ranged between 26 and 4440 with an average of 187 (mean log freq = 4.6). For low frequency words, frequency ranged between 0 and 25 with an average of 9 (mean log freq = 1.8). Frequency was taken from the Barcellona Corpus (1989), which contains 1,500,000 words and incorporates Bortolini et al. (1972). To match the analysis in Shallice et al. (2000), we used log-linear analysis, with categorical variables for frequency and length. In addition, we looked at frequency and length using logistic regression, where frequency and length were continuous variables and length was measured using number of phonemes to allow comparison with subsequent analyses. These regression analyses are powerful, since they are carried out on individual observations (773 different words given in each task). Therefore, it is important to focus on the size of the effect more than on the level of significance. Technical details regarding how the size of the contribution of each variable was assessed are

Table 3 – Rates of correctly produced words by frequency and syllable length in repetition and reading. G^2 is the likelihood ratio χ^2 used in log-linear analyses.

N	High frequency words			Low frequency words			Length effect		Frequency effect	
	2 syll	3 syll	4 syll	2 syll	3 syll	4 syll				
	123	136	66	69	168	159	G^2	p	G^2	p
Repetition										
AC	86	85	85	80	75	66	4.4	n.s.	18.1	<.001
GM	22	7	7.6	16	6	4.4	22	<.001	2.8	n.s.
MC	93	90	79	87	86	74	14	<.001	5.9	.02
MP	4	35	17	22	24	13	0	n.s.	18.1	<.001
RM	85	81	80	65	69	69	3.7	n.s.	27.8	<.001
TC	91	92	86	84	79	74	27	<.001	15.1	<.001
Reading										
AC	86	88	86	85	77	77	.9	n.s.	9.6	<.001
GM	78	75	59	52	58	53	4.5	n.s.	26.7	<.001
MC	73	64	49	62	48	38	21	<.001	12.5	<.001
MP	9	85	96	88	8	80	3.2	n.s.	8.3	<.001
RM	97	94	96	91	90	82	4.8	n.s.	16.0	<.001
TC	88	85	82	87	74	68	8.9	.01	8.7	<.001

provided in Appendix B. Results are presented in Table 4. To assess the effects of other possibly confounding variables we also carried out a series of binary regression including syllabic complexity (measured as number of complex structures as complex onsets, coda etc.), morphological complexity and concreteness in combination with length and frequency. Including these variables only resulted in marginal changes in the results, thus, we are reported any significant effect only in the text.

Several patients showed effects of length by word with both analyses. The only patient who never showed any effect was MP (with neither analyses and in neither task). The patients who showed most consistent effects were MC, RM

Table 4 – Results of logistic regression analyses assessing the contribution of length and frequency to the percentage of words correct. R^2 is the proportion of total variance explained by the full model using summarized data. The percentage of deviance is the amount of deviance explained by a factor over the total deviance explained by the full model (see Appendix B for details).

	Full model	Length/freq interaction		Length		(Log) frequency	
	R^2	% dev	p	% dev	p	% dev	p
AC	.69	1	.5	18	.02	49	<.001
GM	.62	0	1	27	.01	36	.004
MC	.46	2	.7	56	.02	13	.28
MP	.84	6	.2	7	.61	93	<.001
RM	.68	1	.9	17	.02	49	<.001
TC	.89	2	.7	36	<.001	28	<.001
AC	.42	6	.6	13	.55	65	.08
GM	.89	3	.3	4	.9	89	<.001
MC	.90	1	.4	30	<.001	36	<.001
MP	.75	3	.6	10	.5	66	.03
RM	.59	5	.28	21	.05	52	<.001
TC	.76	0	.7	19	.02	47	<.001

and TC (but for RM the effect was not significant in repetition with the log-linear analysis). AC and GM showed effects in repetition, but not in reading. Moreover, AC length effect in repetition disappeared when concreteness was included in the model.

As expected, most patients also showed effects of frequency. MP showed effect of morphological complexity as well as frequency. Among the patients with the most consistent effects of length, RM and TC, but not MC, showed an effect of frequency. TC was the only patient to show any significant effect of syllabic complexity, but only in repetition.

5.4.2. *Frequency and length by phoneme*

Analyses of length using percentage of words correct and percentage of phonemes correct are not guaranteed to produce the same results. Let's suppose, for example, that a patient makes one error every five phonemes, on average, independent of length. This means that many four-phoneme words will be produced completely correctly and many nine-phoneme words incorrectly. Therefore, there will be a length effect by word even if the rate of error per phoneme is constant. The hypothesis of a buffer impairment predicts, more specifically, that the rate of errors per phoneme should increase with word length.

In order to measure length effects by phoneme, individual phonemes that have been produced correctly and incorrectly must be identified, but errors do not always allow an unambiguous classification. To be systematic, we used an algorithm which identified the longest common subsequence in the target and error. *Longest common subsequence* is a computer science term for the largest number of letters that appear in the same relative order in two strings (e.g., *abcde* and *aebdc* have two equally plausible longest common subsequences of 3 letters each, *abc* and *abd*). Formal methods using dynamic programming are guaranteed to find all possible sets with the largest number of phonemes in the correct order (Gusfield, 1997). The fact that more than one set is sometimes identified is not a problem here since we are only interested in the

Please cite this article in press as: Romani C, et al., Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors, Cortex (2010), doi:10.1016/j.cortex.2009.11.004

number of preserved phonemes, not in exactly which ones have been preserved.

5.4.2.1. Results. The average percentage of phonemes correct for words of length four to nine are plotted in Fig. 1 which also reports, for comparison, data for percentage of words totally correct. As predicted, effects of length are more pronounced when calculated in terms of words correct than phonemes correct. This impression is confirmed by a logistic regression analysis using word length and frequency to predict the rate of phonemes correct (see Table 5). Significant effects of length are shown only by RM and TC across tasks and by AC in repetition.

MC, who showed strong effects of length by word, does not show any significant effect by phonemes. This indicates that MC makes more errors on longer words because they offer more chances for errors, but, in fact, his error rate per phoneme is fairly constant. MC was the most severe patient in our group. Note that for an effect to be present by word, but not by phoneme, the rate of errors per phoneme must be at the right level. A rate that is too high will result in all incorrect words; a rate that is too low will result in most words being completely correct.

Table 5 – Results of logistic regression analyses assessing the contribution of length and frequency to the percentage of phonemes correct. R^2 is the proportion of total variance explained by the full model using summarized data. The percentage of deviance is the amount of deviance explained by a factor over the total deviance explained by the full model (see Appendix B for details).

	Full model	Length/freq interaction		Length		(Log) frequency	
	R^2	% dev	*p*	% dev	*p*	% dev	*p*
AC	.62	0	.94	9	.05	63	<.001
GM	.34	5	.35	14	.17	61	<.001
MC	.01	19	.56	98	.24	24	.77
MP	.35	0	.92	11	.16	100	<.001
RM	.54	1	.35	29	<.001	37	<.001
TC	.74	2	.33	23	<.001	45	<.001
AC	.67	0	.91	13	.13	100	<.001
GM	.75	3	.19	5	.27	75	<.001
MC	.73	6	.18	9	.39	76	<.001
MP	.17	2	.80	2	.92	83	.10
RM	.20	4	.45	44	.02	26	.07
TC	.81	18	.01	50	<.001	39	<.001

5.5. *Effects of serial position and length*

5.5.1. *Effects of position only*

In this section, we follow the methodology of previous studies and report error rates by position only, collapsing across different lengths. The positions of words of different lengths (5–9 phonemes) will be normalized to nine standardized positions following the algorithm used by Machtynger and Shallice (2009; also used by Olson, 1995). Using a larger number of positions prevents possible distortions of patterns present in longer words which may occur when positions are accumulated, as with the Wing and Baddeley' algorithm (1980) which standardizes length across five positions only.

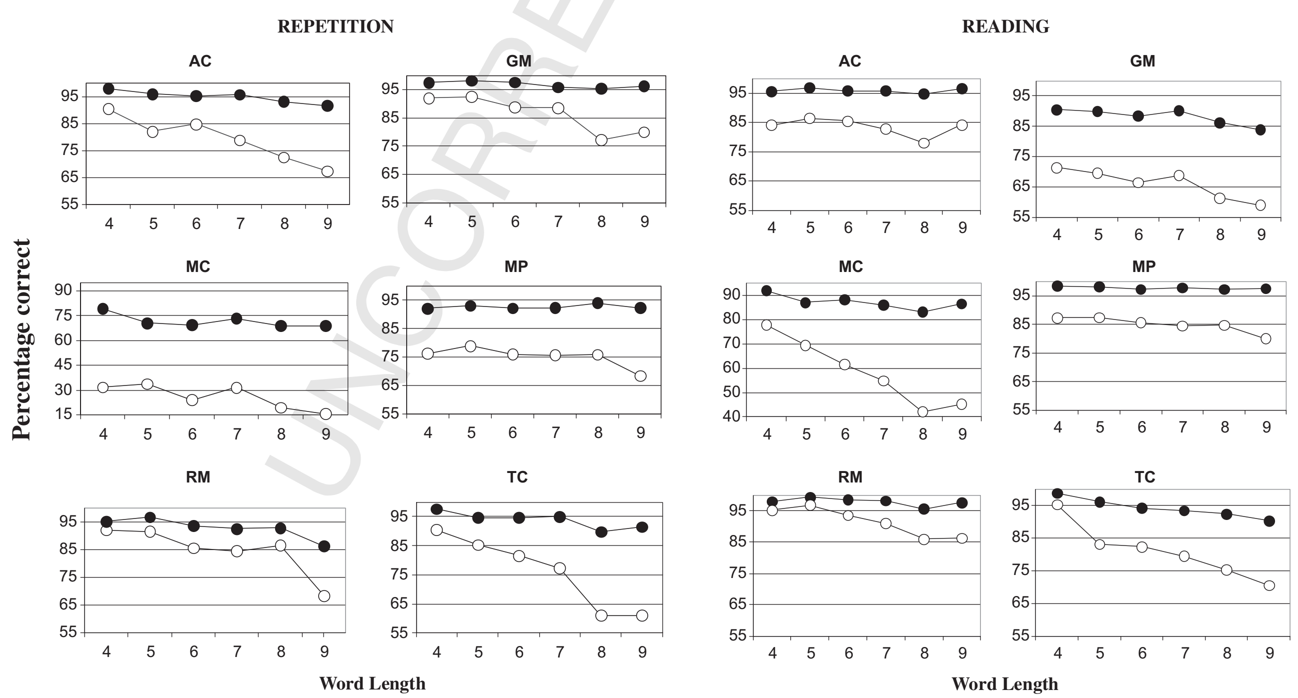


Fig. 1 – Average percentage of words and phonemes correct for words with four to nine phonemes. Closed circles are % phonemes correct; open circles are % words correct. Note that the scale of the y axes is different for MC since he makes more errors than the other patients.

Results are shown in Fig. 2. Only MC's repetition showed some indication of a bow-shaped curve. However, MC makes practically no errors on vowels across positions (99% of errors on consonants). Thus, better performance on the last position is not surprising and there is no bow-shape considering the other positions. All the other curves showed an increasing upward trend (shown most strongly and consistently by RM and TC) with the exception of AC who showed some sign of a trend in the opposite direction.

5.5.2. *Effects of length and position*

Effects of length and position are not independent of each other. A pure position effect (where error rates increase with position, independent of word length) will produce a length effect because longer words have more late positions. A pure length effect (where error rates differ with word length, but are the same across positions) will produce a position effect because only longer words have late positions. What is important for our argument is effects of length *independent* of position. For any given position, the percentage of errors should increase with word length. Thus, serial position curves should be vertically displaced upward for longer words (for an example in ISR see Romani et al., 2008; in the control conditions, if one excludes the first and last positions where performance is close to ceiling, recall for any given position is progressively worse for lists of increasing lengths).

5.5.2.1. Method. To see which phonemes were correct or incorrect for each position, we used again the algorithm for longest common subsequences. This time it was important to identify exactly which positions were preserved. Thus, for ambiguous errors (e.g., in *pizza* → *piza* one could consider the preserved positions to be either 1, 2, 3, 5 or 1, 2, 4, 5), we randomly chose one of the possible scorings (there was no change of pattern when only unambiguous scorings were considered).

5.5.2.2. Results. As shown in Fig. 3, no patient showed a clear separation between the curves for different word lengths, indicating no effects of length independent of position.

Given the different rate of errors on consonants and vowels, we also checked whether different curves were obtained when these errors were analyzed separately. In these analyses, we have also controlled for effects of syllabic position by considering only consonants in simple onsets and only vowels that are flanked by consonants or at word beginning. In spite of noisier data because of the reduced number of observations, results were very much the same as those obtained in the overall analyses. RM and TC continued to show a very systematic increase in errors across positions with both consonants and vowels. MP, who made a large number of errors on vowels, showed a clear upward trend with vowels across tasks.

Qualitative patterns were evaluated statistically using logistic regression. Length and position, but also frequency, were used to predict phonemes correct. Results for the analyses using all errors are reported in Table 6 which also reports results for TC's non-word repetition (to be discussed later).

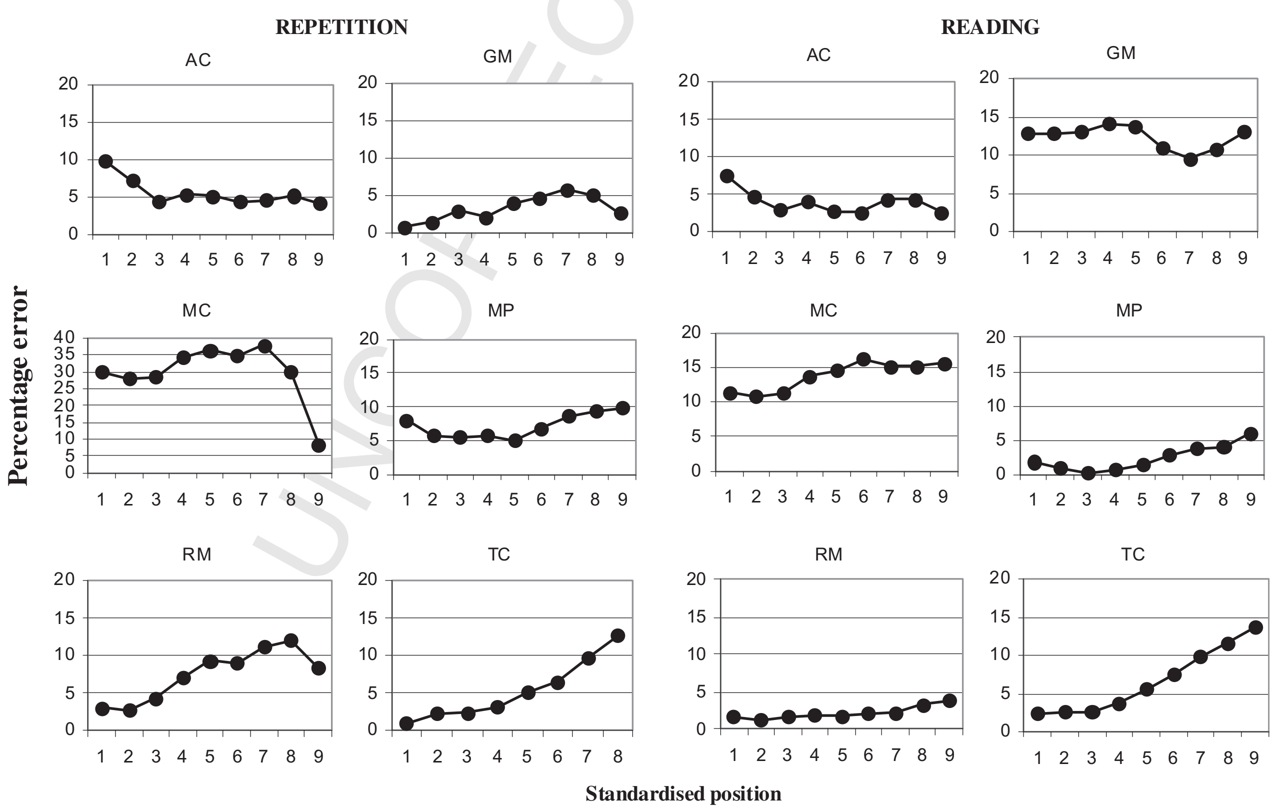


Fig. 2 – Average percentage of phoneme errors by position in the word. Word positions are normalized across nine standard positions and the data are collapsed across words of different length (see text).

Please cite this article in press as: Romani C, et al., Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors, Cortex (2010), doi:10.1016/j.cortex.2009.11.004

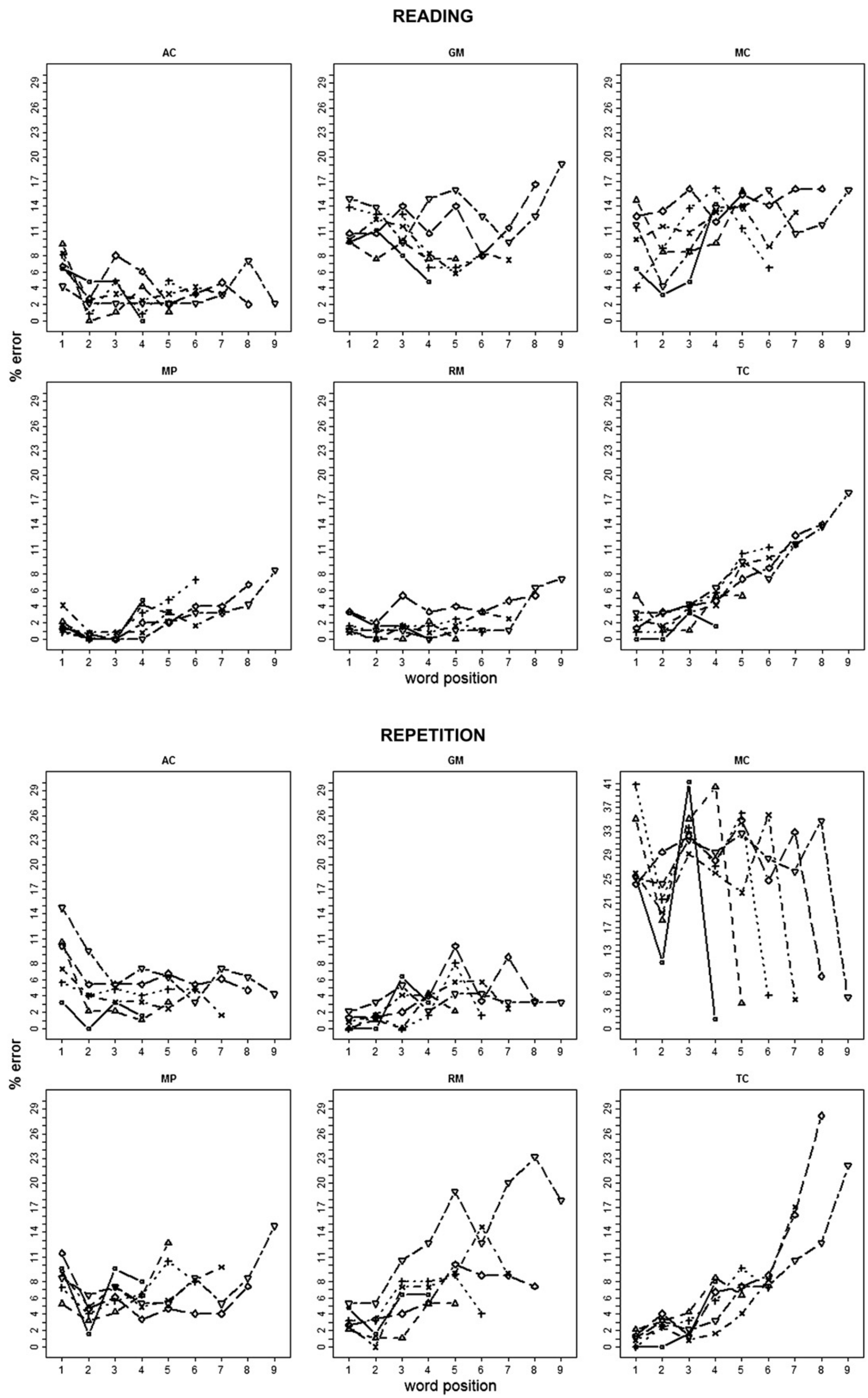


Fig. 3 – Percentage phoneme error at each serial position in words of different lengths. Data are from word reading and repetition. Each line plots data from one word length.

Please cite this article in press as: Romani C, et al., Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors, Cortex (2010), doi:10.1016/j.cortex.2009.11.004

Table 6 – Results of logistic regression analyses assessing the contribution of length, frequency and position to the percentage of phonemes correct. R^2 is the proportion of total variance explained by the full model using summarized data. The percentage of deviance is the amount of deviance explained by a factor over the total deviance explained by the full model (see Appendix B for details).

		Full model	Length/pos interaction		Length		Position		(Log) frequency	
		R^2	% deviance	*p*	% deviance	*p*	% deviance	*p*	% deviance	*p*
Repetition										
Words	AC	.53	0	.69	14	.01	22	<.001	49	<.001
	GM	.27	22	.00	0	.98	44	<.001	34	<.001
	MC	.13	18	.01	25	.01	95	<.001	0	.77
	MP	.06	3	.43	15	.08	8	.20	92	<.001
	RM	.64	0	.44	4	.04	39	<.001	23	<.001
	TC	.87	10	.14	3	.01	82	<.001	9	<.001
Non-words	TC	.65		<.001	30	<.001	51	<.001	–	–
Reading										
Words	AC	.26	15	.04	3	.45	26	.02	74	<.001
	GM	.50	12	.01	3	.20	1	.42	74	<.001
	MC	.28	2	.44	0	.92	16	.02	62	<.001
	MP	.60	0	.68	14	.01	93	<.001	6	.10
	RM	.45	5	.27	6	.23	42	<.001	14	.07
	TC	.90	3	.04	0	.88	73	<.001	7	<.001

With the exception of GM, all other patients showed a significant effect of length in repetition. However, the size of the effect is more important than the level of significance and in most patients this contribution is minimal (exceptions are AC in repetition and MP in reading). Position made a much stronger contribution. In two patients – RM and TC – this contribution was consistent across tasks. TC showed particularly strong effects with position accounting for 70% and 63% of variance in repetition and reading respectively. The qualitative characteristics of these position patterns have already been described above.

5.5.2.3. Discussion. Effects of length by phoneme, possibly the main indicator of a short-term memory problem, are not strong or consistent in this series of patients. In the previous section, we reported strong effects in several patients (e.g., in AC repetition and in RM and TC repetition and reading). Here, however, we show that these effects are almost totally mediated by serial position effects. RM and TC make more errors on longer words, but only because these have late positions which are more error prone. We do not have a good explanation for AC's length effects, but we would be reluctant to attribute them to a buffer component given that: a) they occur together with position effects that are in the opposite direction from what is predicted by a buffer deficit; b) they account for a small amount of variation in repetition; and c) they are not present in reading. MC, who showed some indication of a bow-shaped effect, also showed very small and task-inconsistent length effects.

Given these results, one could decide to consider serially increasing positional effects, and not length effects, to be the hallmark of a buffer impairment. This is, after all, what is predicted by gradient models like Page and Norris (1998; see also Miller and Ellis, 1987; Schiller et al., 2001), and more generally by the hypothesis that phoneme activation decays while some serial operation is carried out. RM, but especially TC, showed strong and consistent effects of this type. In the next section, we examine whether TC's serial position effects can be attributed to a buffer impairment. RM was not available for further testing.

5.6. *Linearly increasing positional effects in TC: do they are arise from a buffer impairment?*

It is important to assess whether TC's serial position effects hold across different error types or whether they are the consequence of high rates of fragments and morphological errors which would affect the last word positions. If TC's errors result mainly from a buffer impairment, results should not change when these errors are removed from the analyses. Moreover, the same results should be obtained with words and non-words, although non-words may be more affected. Instead, if TC suffers from different impairments – a lexical impairment affecting mainly production of words and a buffer impairment affecting mainly the production of non-words – results may be different. With words, linearly increasing effects may be caused by a reduced lexical input which penalizes later positions, but with non-words, bow-shaped effects may be caused by difficulties in temporary activation. As indication of performance being affected by buffer limitations, non-words may also show position-independent length effects and higher rates of transposition errors.

TC was given 225 non-words to repeat. Seventy-five were monosyllabic, 75 bisyllabic and 75 trisyllabic. The monosyllabic non-words consisted of 12 simple CV syllables, 47 CCV syllables and 16 CCCV syllables. The bi-syllabic and tri-syllabic non-words had the same initial syllables as the monosyllabic stimuli with the addition of one or two simple CV syllables. The added syllables always consisted of the consonants /p/, /t/, /k/ combined with the vowels /a/, /o/, /i/ and /e/.

5.6.1. *Results*

Serial position curves obtained with non-words and with words after removing fragments and morphological errors are shown in Fig. 4. With words, TC continues to show the linear, serially increasing pattern that we have shown all along. With non-words, instead, the serial position curve is clearly different. It is not simply shifted downwards, but it is bow

Please cite this article in press as: Romani C, et al., Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors, Cortex (2010), doi:10.1016/j.cortex.2009.11.004

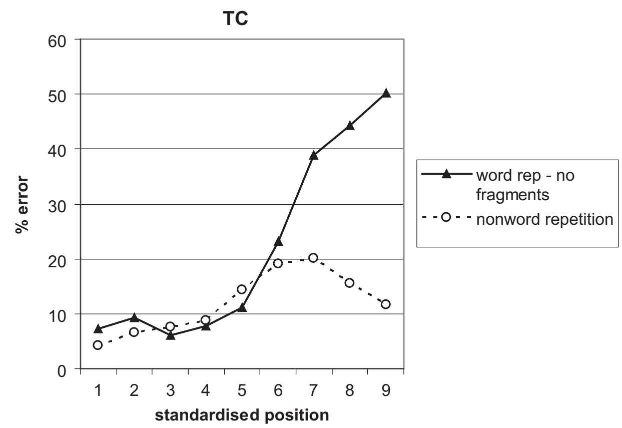


Fig. 4 – TC's percentage of phoneme error as a function of position. Word repetition, excluding fragments and morphological errors, is compared to non-word repetition.

shaped with recency effects for the last positions. A quadratic component is significant with non-words (analysis of deviance $\chi^2 = 31.5$, $p < .001$), but absent with words (analysis of deviance $\chi^2 = 1.4$, $p = .49$; fragments excluded). Any indication of curvature is in the wrong direction.

With non-words, TC also shows much stronger length effects. He made 12%, 29% and 80% errors on the mono-, bi- and tri-syllabic non-words, respectively. Table 6 (above) shows that length contributes to TC's non-word repetition much more than it contributes to word repetition in any other patient and this effect is independent of position. Phoneme error rates are higher in longer non-words even for the same position. Finally, more transposition errors are made by TC in non-word repetition than in word repetition [1/98 = 1% *vs* 10/107 = 9.3%; $\chi^2(1) = 6.98$, $p = .008$].

5.6.2. *Discussion*

With words, TC consistently showed linearly increasing serial position effects. This pattern was present across tasks (reading and repetition), across consonants and vowels, and across type of errors (i.e., it persisted when fragments and morphological errors where eliminated from the analysis). However, the same pattern was not shown with non-words which, instead, showed the bow-shaped function associated with a buffer deficit. These different serial position curves make it unlikely that the word and non-word patterns result from a single impaired process. Instead, they suggest that TC has two problems: (1) a buffer impairment that affects non-words; and (2) a problem with phoneme selection that affects words (see Ward and Romani, 1998; Glasspool et al., 2006). This second problem could be similar to that affecting patient BA in the orthographic domain (Ward and Romani, 1998).

BA's spelling errors also increased with serial position, but a buffer impairment was ruled out by a number of inconsistent results (a different bow-shaped serial position curve in delayed copy; a difficulty with word endings even in backwards writing; strong lexical–semantic effects). Like BA, TC could also suffer from a deficit in activating segments from lexical representations. If letters and phonemes are selected using an activation gradient, weaker activation levels for later positions will produce the serial position effects observed in the patients. This is the same account that has been suggested for what have been called Type-B buffer patients (Cipollotti et al., 2004; Glasspool et al., 2006; see General Discussion for more details).

TC's results, instead, contrast with those of Schiller et al. (2001). They described two patients, TH and PB, who made segmental errors in writing words and non-words and in both tasks showed linearly increasing positional effects. This led the authors to hypothesize a buffer impairment affecting both words and non-words. Schiller et al. supported their interpretation by showing that both patients performed very well with end letters in a fill-in-the-blank task indicating intact lexical knowledge. In contrast, Schiller et al. suggest that more traditional bow-shaped functions could arise at the lexical level. Our results are in direct contrast with this hypothesis, since TC shows a linearly increasing function with words and a bow-shaped function with non-words. This suggests that the bow-shaped effects should be linked to a damaged buffer, consistent with a large literature showing this type of effect in ISR and, more recently, in single non-word repetition (Gupta et al., 2005).

6. General discussion

Our study aimed to answer two related questions. The first was whether one could characterize the phonological activation needed during single word production as a buffer. This would equate the activation needed in single word production with that needed in non-word repetition, serial recall and connected speech. A strong version of this hypothesis, in fact, would imply that there is only one type of phonological activation and all phonological errors have the same source.

Our results provide evidence against this hypothesis. Our patients made phonological errors with the same general characteristics previously associated with a buffer, but none of them showed the length and positional effects expected from a buffer impairment. No patient showed consistent effects of length by phoneme across word reading and repetition and no patient showed clear bow-shaped serial position curves in either word repetition or word reading. TC, who showed strong linearly increasing serial position effects across tasks, did not show the same effects in non-word repetition. These results indicate that the phonological errors made in single word production do not derive from a buffer impairment. On the contrary, they could stem from deficits in phoneme selection rather than phoneme maintenance.

Although we found no evidence of buffer limitations with words, we did find evidence with non-words. Only TC was tested with non-words, but with these he showed both a bow-shaped effect of position and a position-independent effect of length on phoneme error rates. This result strengthens other results from the literature which highlight similarities between non-word repetition and ISR (see Gupta et al., 2005).

These results make it difficult to maintain that there is a single kind of phonological activation. Instead, they support a distinction between phonological short-term memory resources, which are involved in the temporary retention of a novel sequence of units, and phonological lexical resources, which are involved in retaining a sequence of phonemes in a more permanent way. This means endorsing a more general

Please cite this article in press as: Romani C, et al., Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors, Cortex (2010), doi:10.1016/j.cortex.2009.11.004

distinction between resources involved in representing and retrieving information and memory resources involved in their temporary activation (see also Martin and Breedin, 1992; Oakhill and Kyle, 2000; Schwartz et al., 2004; Romani et al., 2008). Following this view, the term '*buffer*' should be reserved for the sustained activation of novel sequences and not used in lexical retrieval.

The second question addressed by our study was whether one could still find evidence that a buffer was implicated in single word production, once lexical and buffer activations were distinguished. Patients could show characteristics consistent with either a deficit of phoneme selection or a buffer deficit. However, we found no patients with the second set of characteristics. Since we have only tested a limited number of patients, it is possible that such a patient will be described in the future. The most parsimonious conclusion at this point, however, is that the lexicon maintains phoneme activation for words and this makes a buffer redundant. Fig. 5 shows the different effect that eliminating or reducing buffer resources would have on word and non-word production following this view (the same buffer will be involved in retaining multiple words, although this is not shown for simplicity).

With words, lexical activation guarantees that phonemes remain active for the time necessary to complete articulatory planning, even in the absence of buffer resources. This is accomplished though connections between word nodes and phoneme nodes and through a strong representation of syllable structure which maintains phoneme order (see Romani et al., submitted for publication). With non-words, instead, lexical representations are only temporary. In the absence of a buffer, they will decay quickly, resulting in phonological errors. Note that according to this model, word production does not 'bypass' a phonological buffer. Rather these resources are not needed in the context of lexical activation. Since we have assumed that lexical representations are impaired in our patients, one may wonder why we do not see more of a role of a phonological buffer in our patients. However, as the errors of the patients demonstrate, damage to the lexical representations is only slight. The syllabic structure of the words is very well preserved with errors involving mostly individual phoneme substitutions (see also Romani and Galluzzi, submitted for publication). Lexical damage will have to be much more severe to see buffer resources to come into play even for single word production.

Our lack of evidence for a phonological buffer in word production also contrasts with the more positive evidence for a graphemic buffer. Patients with alleged orthographic buffer impairments have shown bow-shaped serial position curves and much steeper length effects even with words. For example, the difference in percentage correct between 4 and 8 letters words was 71.3% for LB (94.4–23.1%; Caramazza and Miceli, 1990) and 66.4% for AS: (81.3–14.9%; Jonsdottir et al., 1996). In our patients, differences between 4 and 8 phoneme words ranged between 29.4% (TC) and .4% (MP) in repetition and between 35.8% (MC) and 9.2% (RM) in reading. Orthographic buffer patients also displayed much higher rates of order errors: LB and AS made 21% and 22% transpositions respectively (see Glasspool et al., 2006), while our patients made a maximum of 6% and 7% transpositions in repetition and reading respectively.

Why should a buffer be involved in producing written words, but not spoken words? One possibility is that writing is normally much more time-consuming than articulation. Patients with fast decay of lexical activation in the orthographic domain may end up needing to support words with buffer resources and be affected when these are impaired. Speech will not be equally affected because representations have to be retained for much less time. This will predict that one could see evidence of capacity limitations in word production in patients where articulatory planning is very slow and effortful. Moreover, one could see effects of capacity limitation in spoken word production in patients with semantic dementia where some words have lost their semantic and/or lexical specification and became functionally equivalent to non-words (see Knott et al., 1997; Jefferies et al., 2006). Finding effects of capacity limitations in these conditions will show that the lack of these effects in normal circumstances is theoretically important and not due to methodological difficulties.

6.1. *Computational models*

The number of computational models investigating the issue of memory for serial order is large enough to prevent a detailed consideration of each of them. The general implication of our results, however, is that different serial ordering mechanisms are involved in maintaining phoneme order in the long term (as in lexical representations) and in the short term (as in non-word repetition, serial recall and spontaneous speech). We can consider how existing computational models represent this difference.

The only model that has explicitly addressed the relation between different production tasks is that of Gupta (see Gupta, 1996; Gupta and MacWhinney, 1997; Martin and Gupta, 2004). This model distinguishes the long-term representation of order in known words – the weights of lexical-sub-lexical connections – from a temporary representation of order in novel words – a sequencing mechanism with the same function of our phonological buffer. Thus, Gupta allows word and non-word production to be differently affected by brain-damage. This model, however, does not directly address the issue of how words and non-words may be affected in *qualitatively* different ways (it is more interested in the similarities between non-word repetition, ISR and word learning). This question, instead, is addressed by the model of Glasspool and Houghton (Glasspool and Houghton, 2005; and Glasspool et al., 2006; from now on G&H model) which has simulated different error patterns possibly arising from lexical or buffer damage.

The G&H model is part of a class of models which are known as competitive queuing models because simultaneously activated units compete for selection at the output level. A competitive filter picks, at consecutive points in time, the most activated unit and then inhibits it, so that the next unit can be selected. An activation gradient (with levels of activation progressively decreasing from the beginning to the end of the word) ensures that letters (or phonemes) are picked in the right order. These models have been applied mostly to the orthographic domain, but they are relevant here because they can be damaged in ways which produce different patterns of segmental errors (see Cipollotti et al., 2004). The more traditional buffer pattern (displayed by what Glasspool et al., 2006, called Type-A buffer patients) can be obtained by

Please cite this article in press as: Romani C, et al., Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors, Cortex (2010), doi:10.1016/j.cortex.2009.11.004

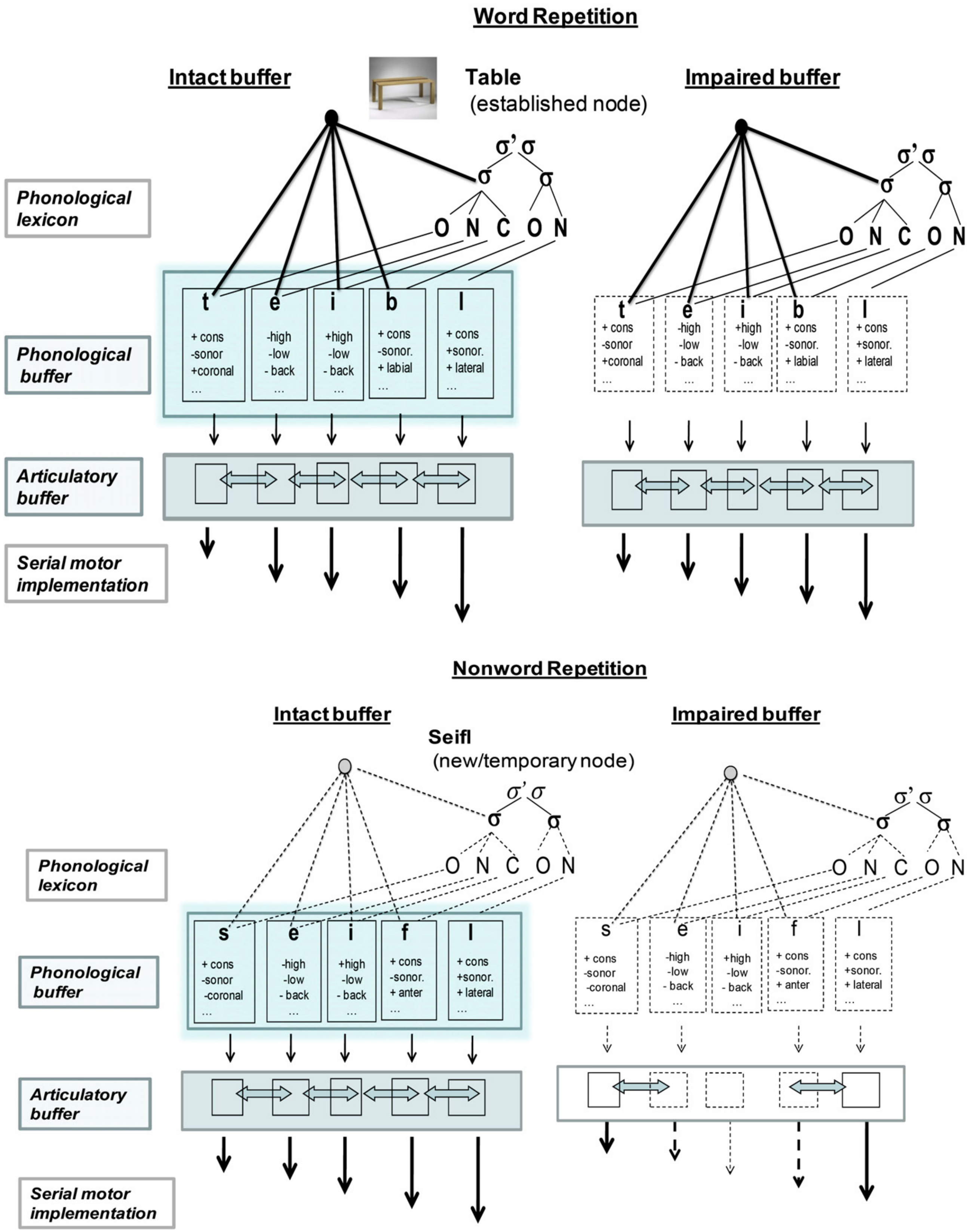


Fig. 5 – A model outlining a distinction between representational resources (the phonological lexicon) and memory resources (buffer components). The buffer is represented as a highlighting of lexical representations stressing that it is an activation and ordering function rather than a separate representational level, as in more traditional box-and-arrows models. The articulatory buffer represents targets in the context of preceding and following phonemes. The length of arrows at the motor implementation level represents time after onset of production.

adding noise at the level of the competitive filter which, like a buffer, encodes positional information for a limited set of units. This manipulation results in: 1) errors that are mostly segmental, with a predominance of substitutions; 2) strong effects of word length; 3) bow-shaped serial position effects; 4) the same patterns of errors across words and non-words, although words are less affected. A more central lexical impairment (displayed by what they called Type-B buffer patients) can be simulated, instead, by reducing the activation gradients supplied by lexical nodes to the corresponding segments. This results in 1) linearly increasing positional effects; 2) stronger effects of lexical variables, and 3) a prevalence of deletions and/or fragment errors and very few transpositions.

Could the G&H model explain the patterns of phonological errors seen in our patients? TC and, to a lesser extent, RM are well explained by a lexical impairment caused by an overall depression of the activation gradient. They show linearly increasing error functions. A reduction in lexical activation would have a more dramatic influence on final positions since these receive less activation to start with. Moreover, reduced lexical activation would produce more failures to activate letters and, therefore, more deletion and fragment errors which are common in these patients. One could further argue that the bow-shaped serial position curve obtained by TC in non-word repetition is caused by a superimposed buffer impairment (noise in the competitive filter). The challenge, however, is to demonstrate that this second impairment has different consequences for words and non-words. It will have to be shown that a lexical input – because of a strong representation of serial order – has the ability to minimize the interference effects responsible for a bow-shaped curve so that only the effects of a linear gradient are visible.

In the G&H model, the buffer is equated with a selection mechanism and the representation of order at the lexical level with an activation gradient. In other models, the buffer is equated with the activation gradient itself. Examples are the Primacy model of Page and Norris (1998, see also Page et al., 2007) and the start–end model by Henson (1998). Still in another model, by Botvinick and Plaut (2006) serial order is retained by very different mechanism at the lexical level and in the short term. Botvinick and Plaut have argued for a distinction between activation models and context models. ***Activation models*** – like the Primacy model of Page and Norris and their own recursive network model – represent serial order though patterns of activation which conjointly involve positional and identity information. In contrast, ***context models*** represent serial order by linking identity information to a separate representation of the context in which the items have been presented (Houghton, 1990; Burgess and Hitch, 1992; Henson, 1998; Brown et al., 2000). Botvinick and Plaut (2006) argue that activation models are best suited to represent patterns of regularity as, for example, phonotactic constraints which are a characteristic of stored representations. Context models, instead, are best suited to represent temporary activation. A possibility, therefore, is to envision hybrid models where a more ***permanent*** representation of the order of phonemes is accomplished through ***activation*** patterns while a ***temporary*** representation (as in non-words) is accomplished though ***context*** vectors.

6.2. *Conclusion*

Our results show the advantage of using detailed statistical modelling of phonological errors to refine models of speech production. Our main result is that phonological segmental errors do not necessarily arise because of capacity limitations. Evidence of capacity limitations are shown with non-words, but not with words. It is possible that evidence for buffer involvement in single word production will be provided at a later point. However, the most parsimonious model at present is one where short-term memory resources are only involved in the retention of novel sequences (such as non-word repetition, serial recall, and spontaneous speech). Our results offer a challenge to existing computational models. Models should include different resources for word and non-word processing so that only non-words are affected by capacity limitations (see also Hanley and Kay, 1997 and Hanley et al., 2002 for dissociations between word and non-word repetition in aphasic patients). They should explain why different positional effect (linearly increasing and bow shaped, but also flat, as in AC) occur for different stimuli and different patients.

Acknowledgements

This research has been partially funded by the British Accademy Grant ref LRG-45609 to the first author. We are deeply grateful to all the patients reported in this study for their endurance and commitment during many hours of testing. We would like to thank Prof. Luigi Pizzamiglio and to Dr Alba Appicciafuoco for providing access to the patients. We would like all the speech therapists at Clinica Santa Lucia and Villa Fulvia for their great help with testing the patients, and especially, Dr Ivana Bureca at Clinica Santa Lucia.

Appendix A.

Level of severity measured as relative proportion of errors involving single phoneme transformations (per word) versus double transformations and more complex transformations (for comparison with buffer patients). Errors involving two adjacent segments are not included among the double errors. It is unclear whether this applies to the analyses carried out in previous studies. Complex errors include errors affecting three or more phonemes, sequences, fragments and no responses.

	Single errors		Double errors		More complex	
	One phoneme		Two phonemes		Total	
	N	%	N	%	N	%
Repetition						
AC	72	43	58	35	36	22
GM	82	55	41	28	25	17
MC	166	19	284	33	419	48
MP	57	35	51	32	53	33
RM	93	48	12	6	88	46
TC	98	49	36	18	68	34
Total	568	33	482	28	689	40

Appendix A – (continued)

	Single errors		Double errors		More complex	
	One phoneme		Two phonemes		Total	
	N	%	N	%	N	%
Reading						
AC	85	59	32	22	26	18
GM	120	43	48	17	108	39
MC	164	35	143	31	156	34
MP	62	67	10	11	21	23
RM	38	51	13	18	23	31
TC	90	49	10	5	82	45
Total	559	45	256	21	416	34

Appendix B. Calculating contribution of different variables in the regression analyses

In the regression analyses, the influence of each term was assessed by comparing models with and without the term included. For example, the influence of the frequency by length interaction was assessed by comparing the variance accounted for by models with and without the interaction term. The influence of length was assessed by comparing a model with frequency entered first and length second (but with no interaction) to a model with frequency only. In other words, critical terms were always entered last, measuring the variability accounted for *after* the other terms had been included. The contribution of individual factors was quantified using deviance (the maximum likelihood equivalent to variance) expressed as a percentage of the deviance accounted for by the full model (i.e., null deviance – full model deviance; Agresti, 2002). The fit of a full model (e.g., length + frequency + length × frequency) model was measured by correlating predicted and observed values for *summarized* data. That is, the model was used to predict the probability correct for individual words. Observed and predicted means were then calculated for each word length in high and low frequency categories, and the measure of fit was the correlation between observed and predicted means (full model R^2). This baseline measure tells us how well the best of the models accounts for the observed data. Percentage deviances for individual factors were converted to R^2 terms for familiarity by multiplying the percentage deviance by the full model R^2. Because we measure the influence of variables entered last and there is usually some overlap in variance accounted for by different terms, the individual R^2 values do not usually sum up to the full model R^2. Because relationships between variables can be complex, however, the contributions of *individual* length, frequency or interaction terms could, on some occasions, sum to more than the full model R^2.

REFERENCES

Agresti A. *Categorical Data Analysis*. Hoboken, N.J.: John Wiley & Sons, 2002.

Aliminosa D, McCloskey M, Goodman-Schulman RA, and Sokol SM. Remediation of acquired dysgraphia as a technique for testing interpretations of deficits. *Aphasiology*, 7: 55–69, 1993.

Archibald LMD and Gathercole SE. Nonword repetition and serial recall: Equivalent measures of verbal short-term memory? *Applied Psycholinguistics*, 28: 587–606, 2007.

Baddeley A. *Human Memory: Theory and Practice*. Hove: Erlbaum, 1990.

Barcellona Corpus di Italiano Scritto Contemporaneo. Istituto di Linguistica Computazionale del CNR di Pisa. Unpublished Manuscript, 1989.

Berg T. A structural account of phonological paraphasias. *Brain and Language*, 94: 104–129, 2005.

Bisiacchi PS, Cipolotti L, and Denes G. Impairment in processing meaningless verbal material in several modalities – The relationship between short-term-memory and phonological skills. *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*, 41: 293–319, 1989.

Bortolini V, Tavaglini C, and Zampolli A. *Lessico di Frequenza della Lingua Italiana Contemporanea*. Milano: Garzanti, 1972.

Botvinick M and Plaut DC. Short-term memory for serial order: A recurrent neural network model. *Psychological Review*, 113: 201–233, 2006.

Bub D, Black S, Howell J, and Kertesz A. Speech output processes and reading. In Coltheart M, Sartori G, and Job R (Eds), *The Cognitive Neuropsychology of Language*. Hove, U.K.: Lawrence Erlbaum Associates, 1987.

Buchwald A and Rapp B. Consonant and vowels in orthographic representations. *Cognitive Neuropsychology*, 23: 308–337, 2006.

Burgess N and Hitch GJ. Towards a network model of the articulatory loop. *Journal of Memory and Language*, 31: 429–460, 1992.

Caramazza A, Miceli G, and Villa G. The role of the (output) phonological buffer in reading, writing, and repetition. *Cognitive Neuropsychology*, 3: 37–76, 1986.

Caramazza A, Miceli G, Villa G, and Romani C. The role of the graphemic buffer in spelling – Evidence from a case of acquired dysgraphia. *Cognition*, 26: 59–85, 1987. Q7

Campoy G. The effect of word length in short-term memory: Is rehearsal necessary? *The Quarterly Journal of Experimental Psychology*, 61: 724–734, 2008.

Cipollotti L, Bird C, Glasspool D, and Shallice TS. The impact of deep dysgraphia on graphemic output buffer disorders. *Neurocase*, 10: 405–419, 2004.

De Partz MP. Deficit of the graphemic buffer: Effects of a written lexical segmentation strategy. *Neuropsychological Rehabilitation*, 5: 129–147, 1995.

Dell GS. A spreading-activation theory of retrieval in sentence production. *Psychological Review*, 93: 283–321, 1986. Q8

Dell GS, Schwartz MF, Martin N, Saffran EM, and Gagnon DA. Lexical access in aphasic and nonaphasic speakers. *Psychological Review*, 104: 801–838, 1997a.

Dell GS, Burger LK, and Svec WR. Language production and serial order: A functional analysis and a model. *Psychological Review*, 104: 123–147, 1997b. Q9

Ellis AW. Errors in speech and short-term-memory – The effects of phonemic similarity and syllable position. *Journal of Verbal Learning and Verbal Behavior*, 19: 624–634, 1980.

Foygel D and Dell GS. Models of impaired lexical access in speech production. *Journal of Memory and Language*, 43: 182–216, 2000.

Fromkin VA. *Speech Errors as Linguistic Evidence*. The Hague: Mouton, 1973.

Please cite this article in press as: Romani C, et al., Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors, Cortex (2010), doi:10.1016/j.cortex.2009.11.004

Garcia-Orza J and León-Carrión J. Lexical effects in verbal STM: Evidence from a phonological output buffer patient. *Brain and Language*, 95: 44–45, 2005.

Garrett MF. In Butterworth B (Ed), *Language Production*. Speech and Talk, vol. 1. New York: Academic Press, 1980: 177–220.

Glasspool DW and Houghton G. Serial order and consonant-vowel structure in a graphemic output buffer model. *Brain and Language*, 94: 304–330, 2005.

Glasspool DW, Shallice T, and Cipolotti L. Towards a unified process model for graphemic buffer disorder and deep dysgraphia. *Cognitive Neuropsychology*, 23: 479–512, 2006.

Gupta P. Primacy and recency in nonword repetition. *Memory*, 13: 318–324, 2005.

Gupta P, Lipinski J, Abbs B, and Lin PH. Serial position effects in nonword repetition. *Journal of Memory and Language*, 53: 141–162, 2005.

Gusfield D. *Algorithms on Strings, Trees, and Sequences: Computer Science and Computational Biology*. Cambridge: Cambridge University Press, 1997.

Hanley JR and Kay J. An effect of imageability on the production of phonological errors in auditory repetition. *Cognitive Neuropsychology*, 14: 1065–1084, 1997.

Hanley JR, Kay J, and Edwards M. Imageability effects, phonological errors, and the relationship between auditory repetition and picture naming: Implications for models of auditory repetition. *Cognitive Neuropsychology*, 19: 193–206, 2002.

Hartley T and Houghton G. A linguistically constrained model of short-term memory for nonwords. *Journal of Memory and Language*, 35: 1–31, 1996.

Henson RNA. Short-term memory for serial order: The start-end model. *Cognitive Psychology*, 36: 73–137, 1998.

Houghton G. The problem of serial order: A neural network model of sequence learning and recall. In Dale R, Mellish C, and Zock M (Eds), *Current Research in Natural Language Generation*. London: Academic Press, 1990.

Howard D and Franklin S. Dissociations between component mechanisms in short-term memory: Evidence from brain-damaged patients. In Meyer DE and Kornblum S (Eds), *Attention and Performance XIV: Synergies in Experimental Psychology, Artificial Intelligence and Cognitive Neuroscience*. Cambridge, MA: MIT Press, 1993.

Howard D and Nickels L. Separating input and output phonology: Semantic, phonological, and orthographic effects in short-term memory impairment. *Cognitive Neuropsychology*, 22: 42–77, 2005.

Hulme C, Roodenrys S, Brown G, and Mercer R. The role of long-term-memory mechanisms in memory span. *British Journal of Psychology*, 86: 527–536, 1995.

Hulme C, Roodenrys S, Schweickert R, Brown GDA, Martin S, and Stuart G. Word-frequency effects on short-term memory tasks: Evidence for a redintegration process in immediate serial recall. *Journal of Experimental Psychology: Learning Memory and Cognition*, 23: 1217–1232, 1997.

Jacquemot C and Scott S. What is the relationship between phonological short-term memory and speech processing? *Trends in Cognitive Sciences*, 10: 480–486, 2006.

Jefferies E, Frankish C, and Rambon Ralph MA. Lexical and semantic binding in verbal short-term memory. *Journal of Memory and Language*, 54: 81–98, 2006.

Jonsdottir MK, Shallice T, and Wise R. Phonological mediation and the graphemic buffer disorder in spelling: Cross-language differences? *Cognition*, 59: 169–197, 1996.

Katz RB. Limited retention of information in the graphemic buffer. *Cortex*, 27: 111–119, 1991.

Knott R, Patterson K, and Hodges JR. Lexical and semantic binding effects in short-term memory: Evidence from semantic dementia. *Cognitive Neuropsychology*, 14: 1165–1216, 1997.

Levelt WJM, Roelofs A, and Meyer AS. A theory of lexical access in speech production. *Behavioural and Brain Sciences*, 22: 1–38, 1999.

Machtynger J and Shallice T. Normalising serial position analyses: The proportional accountability algorithm. *Cognitive Neuropsychology*, 26: 217–222, 2009.

Martin N and Gupta P. Processing and verbal short-term memory: Evidence from associations and dissociations. *Cognitive Neuropsychology*, 21: 213–228, 2004.

Martin RC and Breedin SD. Dissociations between speech perception and phonological short-term-memory deficits. *Cognitive Neuropsychology*, 9: 509–534, 1992.

Martin RC, Lesch MF, and Bartha MC. Independence of input and output phonology in word processing and short-term memory. *Journal of Memory and Language*, 41: 3–29, 1999.

Martin N and Saffran EM. Language and auditory-verbal short-term memory impairments: Evidence for common underlying processes. *Cognitive Neuropsychology*, 14: 641–682, 1997.

Meyer AS. The time course of phonological encoding in language production – The encoding of successive syllables of a word. *Journal of Memory and Language*, 29: 524–545, 1990.

Meyer AS, Roelofs A, and Levelt WJM. Word length effects in object naming: The role of a response criterion. *Journal of Memory and Language*, 48: 131–147, 2003.

Meyer AS and Schriefers H. Phonological facilitation in picture word interference experiments – Effects of stimulus onset asynchrony and types of interfering stimuli. *Journal of Experimental Psychology: Learning Memory and Cognition*, 17: 1146–1160, 1991.

Miller D and Ellis A. Speech and writing errors in ''neologistic jargonaphasia'': A lexical activation hypothesis. In Coltheart M, Sartori G, and Job R (Eds), *The Cognitive Neuropsychology of Language*. London: Erlbaum Associates Ltd., 1987.

Nickels L and Howard D. Dissociating effects of number of phonemes, number of syllables, and syllabic complexity on word production in aphasia: It's the number of phonemes that counts. *Cognitive Neuropsychology*, 21: 57–78, 2004.

Nickels L and Howard D. Aphasic naming – What matters. *Neuropsychologia*, 33: 1281–1303, 1995.

Nickels LA, Howard D, and Best WM. Fractionating the articulatory loop: Dissociations and associations in phonological recoding in aphasia. *Brain and Language*, 56: 161–182, 1997.

Oakhill J and Kyle F. The relation between phonological awareness and working memory. *Journal of Experimental Child Psychology*, 75: 152–164, 2000.

Olson AC. Syllables, letter frequency and sound: Orthographic structure in deaf reading and spelling. Unpublished doctoral dissertation, The Johns Hopkins University, Baltimore, 1995.

Olson AC, Romani C, and Halloran L. Localizing the deficit in a case of jargonaphasia. *Cognitive Neuropsychology*, 24: 211–238, 2007.

Page MPA, Madge A, Cumming N, and Norris DG. Speech errors and the phonological similarity effect in short-term memory: Evidence suggesting a common locus. *Journal of Memory and Language*, 56: 49–64, 2007.

Page MPA and Norris D. The primacy model: A new model of immediate serial recall. *Psychological Review*, 105: 761–781, 1998.

Posteraro L, Zinelli P, and Mazzucchi A. Selective impairment of the graphemic buffer in acquired dysgraphia – A case-study. *Brain and Language*, 35: 274–286, 1988.

Roelofs A. Spoken language planning and the initiation of articulation. *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*, 55: 465–483, 2002a.

Roelofs A. Syllable structure effects turn out to be word length effects: Comment on Santiago et al. (2000). *Language and Cognitive Processes*, 17: 1–13, 2002b.

Roelofs A. The WEAVER model of word-form encoding in speech production. *Cognition*, 64: 249–284, 1997.

Please cite this article in press as: Romani C, et al., Phonological–lexical activation: A lexical component or an output buffer? Evidence from aphasic errors, Cortex (2010), doi:10.1016/j.cortex.2009.11.004

Romani C. Are there distinct input and output buffers – Evidence from an aphasic patient with an impaired output buffer. *Language and Cognitive Processes*, 7: 131–162, 1992.

Romani C and Galluzzi C. The effects of syllabic complexity on correct repetition in a group of aphasic patients. *Cognitive Neuropsychology*, 22: 817–850, 2005.

Romani C, Olson A, Semenza C, and Granà A. Phonological errors in two aphasic patients: A phonological vs. an articulatory locus of impairment. *Cortex*, 38: 541–567, 2002. Q10

Romani C, Mc Alpine S, Olson A, Tsouknida E, and Martin RC. Length, lexicality and articulatory suppression in immediate serial recall: Evidence against the articulatory loop. *Journal of Memory and Language*, 52: 398–415, 2005.

Romani C, Mc Alpine S, Olson A, and Martin RC. Concreteness effects in different tasks: Evidence for semantic STM. *Quarterly Journal of Experimental Psychology*, 61: 293–324, 2008.

Sage K and Ellis AW. Lexical influences in graphemic buffer disorder. *Cognitive Neuropsychology*, 21: 381–400, 2004.

Santiago J, Mackay DG, Palma A, and Rho C. Sequential activation processes in producing words and syllables: Evidence from picture naming. *Language and Cognitive Processes*, 15: 1–44, 2000.

Santiago J, Mackay DG, and Palma A. Length effects turn out to be syllable structure effects: Response to Roelofs (2002). *Language and Cognitive Processes*, 17: 15–29, 2002.

Schwartz MF, Wilshire CE, Gagnon DA, and Polansky M. Origins of nonword phonological errors in aphasic picture naming. *Cognitive Neuropsychology*, 21: 159–186, 2004.

Service E. The effect of word length on immediate serial recall depends on phonological complexity, not articulatory duration. *Quarterly Journal of Experimental Psychology*, 51A: 283–304, 1998.

Schiller NO, Greenhall JA, Shelton JR, and Caramazza A. Serial order effects in spelling errors: Evidence from two dysgraphic patients. *Neurocase*, 7: 1–14, 2001.

Schriefers H and Teruel E. Phonological facilitation in the production of two-word utterances. *European Journal of Cognitive Psychology*, 11: 17–50, 1999.

Shallice T, Rumiati RI, and Zadini A. The selective impairment of the phonological output buffer. *Cognitive Neuropsychology*, 17: 517–546, 2000.

Shallice T and Warrington EK. Auditory-verbal short-term-memory impairment and conduction aphasia. *Brain and Language*, 4: 479–491, 1977.

Shattuck-Hufnagel S. Speech errors as evidence for a serial-order mechanism in sentence production. In Cooper WE and Walker ECT (Eds), *Sentence Processing: Psycholinguistic Studies Presented to Merrill Garrett*. Hillsdale, N.J.: Lawrence Erlbaum, 1979.

Trojano L and Chiacchio L. Pure dysgraphia with relative sparing of lower-case writing. *Cortex*, 30: 499–507, 1994.

Ward J and Romani C. Serial position effects and lexical activation in spelling: Evidence from a single case study. *Neurocase*, 4: 189–206, 1998. Q11

Ward J, Olson A, and Romani C. Competitive queuing and spelling: Modelling acquired dysgraphia. In Heinke D, Humphreys GW, and Olson A (Eds), *Connectionist Models in Neuroscience*. London: Springer-Verlag, 1998: 25–39.

Ward J and Romani C. Consonant-vowel encoding and ortho-syllables in a case of acquired dysgraphia. *Cognitive Neuropsychology*, 17: 641–663, 2000.

Wheeldon L and Levelt WJM. Monitoring the time course of phonological encoding. *Journal of Memory and Language*, 37: 356–381, 1995.

Wheeldon L and Morgan JL. Phoneme monitoring in internal and external speech. *Language and Cognitive Processes*, 17: 503–535, 2002.

Wing AM and Baddeley AD. *Spelling Errors in Handwriting: a Corpus and a Distributional Analysis*. Academic Press, 1980.

Ziegler W. A nonlinear model of word length effects in apraxia of speech. *Cognitive Neuropsychology*, 22: 603–623, 2005.