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Brain and Language 93 (2005) 106–119

Brain and Language

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What underlies the neuropsychological pattern of irregular > regular past-tense verb production?

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Accepted 11 September 2004
Available online 18 November 2004

Abstract

The disadvantage in producing the past tense of regular relative to irregular verbs shown by some patients with non-fluent aphasia has been alternatively attributed (a) to the failure of a specific rule-based morphological mechanism, or (b) to a more generalised phonological impairment that penalises regular verbs more than irregular owing to the on-average greater phonological complexity of regular past-tense forms. Guided by the second of these two accounts, the current study was designed to identify more specific aspects of phonological deficit that might be associated with the pattern of irregular > regular past-tense production. Non-fluent aphasic patients ($N = 8$) were tested on past-tense verb production tasks and assessed with regard to the impact of three main manipulations in other word-production tasks: (i) insertion of a delay between stimulus and response in repetition; (ii) presence/number of consonant clusters in a target word in repetition; (iii) position of stress within a bi-syllabic word in repetition and picture naming. The performance of all patients deteriorated in delayed repetition; but the patients with the largest discrepancy between regular and irregular past-tense production showed greater sensitivity to the other two manipulations. The phonological nature of the factors that correlated with verb-inflection performance emphasises the role of a phonological deficit in the observed pattern of irregular > regular.

Keywords: Past-tense morphology; Phonology; Broca's aphasia; Connectionist modelling

1. Introduction

The apparent division in language between regular and irregular forms, in particular, with regard to verbs and their past tenses, is a continuing focus of theoretical debate. One major source of evidence in this area comes from adult language disorders consequent on brain injury or disease. Patients with different aphasic profiles have been reported to constitute the two sides of a double dissociation, i.e., some with a significant advantage for regular > irregular and some with the opposite pattern (Bird, Lambon Ralph, Seidenberg, McClelland, & Patterson, 2003; Marslen-Wilson & Tyler, 1997; Patterson, Lambon Ralph, Hodges, & McClelland, 2001; Tyler, de Mornay Davies et al., 2002; Tyler, Randall, & Marslen-Wilson, 2002; Ullman et al., 1997). By the logic of standard neuropsychological inquiry (Shallice, 1988), double dissociation requires a conclusion of separate mechanisms, although this is not the only interpretation available (Plaut, 1995). There is variation amongst different dual-mechanism accounts, for example, the details of the mechanisms proposed by Tyler, de Mornay Davies et al. (2002), Tyler, Randall et al. (2002) are not identical to those in the account of Pinker (1999) and Ullman et al. (1997); but these theories share the principle that a special rule-based morphological process is required for

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0093-934X/$ - see front matter
doi:10.1016/j.bandl.2004.09.001

comprehension and production of the past tense in real regular verbs (and novel verbs) but not for irregular verbs. In this regard, these theories differ from parallel-distributed processing (PDP) accounts in which differences between regular and irregular verbs are hypothesised to arise elsewhere in the language system (Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002; Stemberger, 1995).

According to the PDP account, a relative disadvantage for the regular past tense is explicable in terms of inherent phonological/articulatory differences between regular and irregular past-tense forms. The patients whose performance demonstrates the irregular > regular pattern have non-fluent aphasia. In addition to syntactic problems, their most striking language impairments are in the realm of phonological and articulatory processing (Kurowski, Hazen, & Blumstein, 2003). Burzio (2002) and Hoeffner and McClelland (1993) have argued that regular past-tense forms, especially in words like "typed" or "streaked" which have a long vowel or diphthong followed by a stop consonant followed by an alveolar stop, are unusually difficult both to hear and to say. By contrast, most irregular past tense forms are phonologically simple (compare *type* → *typed* with *write* → *wrote*, and *walk* → *walked* with *run* → *ran*). For a patient with phonological and articulatory deficits, the speech features of regular past-tense words might be expected to incur performance deficits independent of any morphological factors.

Two previous studies by our group were motivated by this phonological hypothesis regarding the irregular > regular side of the neuropsychological double dissociation. In the first study, a disadvantage for regular past-tense verbs was first established for 10 non-fluent aphasic patients on a screening test involving three production tasks (past-tense generation, reading and repetition); this difference was then essentially eliminated when the same patients were tested on the same tasks but with regular and irregular verbs matched for the CVC structure of their past tense forms, as in "stepped" and "slept" (Bird et al., 2003). The second study, comprising a detailed analysis of the errors produced by the same cohort of patients in generating, reading and repeating past-tense verb forms, demonstrated that the predominant errors in all tasks and for all verb types were phonologically related responses (Braber, Patterson, Ellis, & Lambon Ralph, in press). Even those incorrect responses that could be described as morphological errors, such as omission of the regular inflection, fitted neatly with an interpretation that classified them as phonological simplifications of the target forms.

The present study was designed as a third stage of the plan to evaluate a phonological explanation for the irregular > regular pattern of past-tense performance. Eight patients with non-fluent aphasia were tested on past-tense verb production and also on a range of repetition and picture naming measures for which we could manipulate potentially relevant aspects of the stimulus materials and task. Unlike the previous two studies in this series, the selection criteria for patients in this investigation did not include an irregular > regular pattern of past-tense performance on our screening materials. As is apparent from previous research (for example Bird et al., 2003; Ullman et al., 1997), non-fluent aphasic patients are invariably impaired at past-tense production for all verbs; but only a subset of cases show the significant irregular > regular pattern that has been the focus of recent debate. Not requiring this characteristic in the cohort of patients tested here enabled us to place the eight cases on a continuum with respect to their relative success with regular and irregular verbs, and then to ask which factors in other production tasks correlated with extent of the irregular > regular pattern.

Three manipulations were selected that seemed plausible candidates for such a relationship. First, given that regular past-tense forms on average contain more phonemes than their irregular counterparts, we hypothesised that the irregular > regular pattern might be associated with a particularly fragile phonological working memory. We therefore administered a set of tests involving repetition of a spoken word or non-word both immediately and following a brief filled delay. Second, given that so many regular past-tense forms (like "walked" or "typed") end in consonant clusters that should be difficult for a person with impaired articulation, we reasoned that patients characterised by an irregular > regular pattern might be particularly sensitive to this aspect of target words. We therefore measured success in immediate repetition of morphologically simple, monosyllabic words containing consonant clusters at both onset and offset, or at just one, or at neither, of these positions. Finally, on the basis of Burzio's (2002) argument that morphologically regular past-tense verbs tend to be phonologically atypical, we hypothesised that patients characterised by an irregular > regular pattern might be challenged by other atypical phonological features of target words. In English, primary stress in a bi-syllabic word is overwhelmingly likely—approaching 90%—to be on the first rather than the second syllable. We therefore compared repetition and picture naming success for sets of object names with first- vs. second-syllable stress.

2. Methods

2.1. Participants and background assessments

Eight non-fluent aphasic patients (demographic details in Table 1) completed a battery of assessments designed to yield a profile of general language and semantic capabilities (Table 2) as well as more specific phonological abilities (Table 3). The first three cases

Table 1
Age, sex, and neurological history for the eight patients

Patient	Age	Sex	Aetiology/CT Report
AB	63	F	1996 embolic CVA L MCA territory
GN	74	M	1999 L frontal infarct MCA territory, low density L occipital lesion
JL	48	F	1996 L CVA involving temporal, parietal and frontal lobe
GD	66	M	2000 L CVA
PG	68	M	2000 L parietal CVA, L MCA occlusion
DC	40	F	2001 L parietal haematoma
JS	47	F	1997 L CVA
DM	52	M	1998 L subarachnoid haemorrhage with resulting haematoma

Table 2
Performance [raw scores] by the individual patients on a series of neuropsychological and language tests

Patient	Cookie theft words/minute	Digit span F (B)	TROG Blocks/20	Word reading/80 (HIm/40, LIm/40)	Non-word reading/40	Picture naming/64	Word-picture	PPT/52 matching/64
AB	5	3 (2)	8	32 (29, 3)	2	42	62	47
GN	27	4 (2)	10	40 (29, 11)	8	48	60	45
JL	47	5 (3)	19	72 (39, 33)	29	54	64	51
GD	8	8 (2)	13	71 (36, 35)	28	27	63	48
PG	19	4 (0)	14	61 (33, 28)	10	53	63	51
DC	26	6 (1)	15	71 (39, 32)	30	64	64	52
JS	17	4 (2)	11	50 (31, 19)	5	51	62	42
DM	33	3 (2)	10	60 (33, 27)	32	50	61	50

Table 3
Performance [raw scores] by the individual patients on four tests of phonological ability

Patient	Rhyme judgement/48	Rhyme production/24	Phoneme blending/48	Phoneme segmentation/48
AB	42	7	Unable	Unable
GN	35	8	6	28
JL	48	16	32	29
GD	45	18	41	34
PG	32	Unable	Unable	Unable
DC	38	22	38	4
JS	41	8	Unable	25
DM	33	13	Unable	Unable

listed in these tables had participated in the two previous studies in this series (Bird et al., 2003; Braber et al., in press). In all data tables, the individual patients are ordered by the degree of discrepancy between regular and irregular verbs in their performance on tests of past-tense verb production as a proportion of their overall success rate (see the first set of data in Section 3). That is, patient AB showed the largest advantage for irregular over regular past-tense production relative to her general level of performance on the same tests, and DM had the smallest advantage (in fact, he was more successful in producing regular past-tense verbs, though not significantly so).

The criterion for patient selection in the current study was substantial dysfluency in connected speech, operationalised by abnormally slow and laboured production in describing the Cookie Theft picture from the Boston Diagnostic Aphasic Examination (Goodglass & Kaplan, 1983). As indicated in column 2 of Table 2, speech rate across the eight patients on this measure ranged from 5 to 47 words per minute, whereas in a group of similar-aged normal speakers, the slowest rate was 96 words/minute (Bird, Lambon Ralph, Patterson, & Hodges, 2000).

Surprisingly for aphasia of this type, a few of the patients had forward digit spans within the normal range, but all were very poor at backwards span. All patients except JL (who also had the highest speech rate) were impaired at the TROG, a measure of syntactic comprehension (Bishop, 1989). Almost all patients showed an advantage (sometimes substantial, e.g., AB, GN, JS) for reading aloud of high > low imageability words, and a deficit (again sometimes marked: AB, GN, PG, and JS) in non-word reading; both of these are standard characteristics of phonological/deep dyslexia (Lambon Ralph & Graham, 2000; Shallice, 1988). Picture naming success ranged from normal to moderately impaired, but all patients performed well at word-to-picture matching. Even on a more difficult assessment of comprehension, the Pyramids and Palm Trees test of semantic association (Howard & Patterson, 1992), none of the cases (with the possible exception of JS) had more than a mild deficit.

An easy receptive phonological test—the ability to judge whether two spoken words rhyme—yielded scores from normal (JL) to near-normal (AB, GD, and JS) to very abnormal though still above chance (GN, PG, DC, and DM) (Table 3). By contrast, in three tests requiring phonological manipulation and a spoken response—rhyme production, segmentation and blending—all patients were impaired and half of the patients could not even attempt one or more of these tasks despite being given numerous practice examples.

2.2. Main tasks and stimulus materials

As indicated in Section 1, the goal of this investigation was to determine which (if any) of three phonological factors or manipulations would be associated with the extent of an irregular > regular pattern in the participants' past-tense verb production. The testing thus consisted of four main components, as follows:

2.2.1. Past-tense production

The patients all performed three different production tasks: (i) immediate auditory-verbal repetition of past-tense verbs; (ii) reading aloud of printed past-tense verbs; and (iii) generation of past-tense forms in a sentence completion task, e.g. "Today I talk to my friend; yesterday I ______ to my friend" where the patient was asked to use the same verb from the first part of the sentence pair, altering it to its past-tense form to complete the second part. The materials used for this component were the screening assessments from Bird et al. (2003), which consisted of three word sets. The first was a set of 24 regular and 24 irregular verbs matched for frequency and imageability (from Bird et al., and listed in Appendix A of the current paper); these 48 past-tense verbs were tested in all three tasks of sentence completion, repetition, and reading aloud. The second was a list of 20 regular and 20 irregular verbs previously used by Ullman et al. (1997) to test past-tense generation; we administered this set in both sentence completion and repetition. The third, administered for reading only, was a set of 34 past-tense verbs, again half regular and half irregular, employed by Ullman et al. as their 'anterior aphasic reading list.' In the repetition and reading tasks, which are easier and more self-explanatory, the stimulus word was presented only in auditory form for repetition and only in written form for reading; but in the more difficult generation task, in order to encourage the best possible performance from the participants, we presented the materials simultaneously in written and spoken format. The patients were also allowed to engage in an extended practice version of the generation task until it was clear that they understood it.

2.2.2. Delayed repetition

This component of the study was designed to determine whether the (or a) factor relating to disproportionate difficulty with regular past-tense forms might be fragility of phonological working memory. The patients were asked to repeat target words or non-words, both immediately and after a brief filled delay, from three different lists. The first list consisted of 34 pairs of past-tense verbs, where each pair contained one regular and one irregular past-tense form matched for CV structure (e.g., *slapped/swept*, *sprayed/strode*, *called/held*: see Appendix B for a complete list); these items were employed by Bird et al. (2003) to demonstrate that patients with an irregular > regular advantage on past-tense verbs unmatched for phonological structure achieved equivalent scores for regular and irregular on several past-tense production tasks once the two sets were matched in this way. The second list was from the PALPA (Kay, Lesser, & Coltheart, 1992): a total of 80 words varying in frequency and imageability, with 20 words in each of the four sets formed by words high on both of these variables, low on both, or high on one and low on the other. The third list consisted of 48 non-words derived from a set of low-frequency real words by altering two phonemes such that the non-words remained easily pronounceable (e.g., "vality" from *verity* and "telpot" from *despot*: see Appendix C for the full set).

The same experimental procedure was applied for all three lists. The tester first spoke a single target word/non-word. The patient repeated the target to yield a measure of immediate repetition. The tester and patient then counted aloud together from 1 to 5; this distractor task was intended to prevent the patient from rehearsing during the delay but with a task easy enough for all patients, even the most severely aphasic, to manage. At the end of counting, the patient attempted to produce the target word again to yield a measure of delayed repetition. Note that this method results in a somewhat weak manipulation of delay, partly because the delay was short and the filler task relatively easy, but even more so because the patients had just 'practised' the task for each stimulus word shortly before they had to produce it in delayed repetition. A more stringent procedure would have been to test immediate and delayed repetition on different occasions, such that the delayed observations would be uncontaminated by the benefit to the patients of having just produced the word in immediate repetition. We used the procedure indicated here for two reasons: (i) if a correct response in the immediate condition precedes an error in the delayed condition, the researcher can be certain that the delayed error is attributable to the delay rather than to an initial misperception of the target word; (ii) these experiments are slow and difficult for severely aphasic patients, and testing should accordingly be minimised wherever possible.

2.2.3. Repetition of words varying in phonological complexity

The third component of the study was designed to determine whether particular difficulty with regular past-tense forms would be associated with non-morphological phonological complexity in the form of consonant clusters. The stimuli consisted of a total of 96 monosyllabic, monomorphemic, words in three subsets. Each subset contained 32 words formed from 16 pairs of items with the same phonological 'core' but differing in clusters at offset, onset or both. In subset A (example, *pawn/paunch*), the second member of the pair had a more complex offset. In subset B, (example, *tint/stint*), the second word had a more complex onset. In subset C, (example, *lick/blink*), the second word was more complex at both onset and offset. In every subset, each pair was matched for frequency in the Celex database. The 96 words were randomised (with the restriction only that the two words of one pair such as *tint/stint* did not occur within 2 items of each other) and presented to each patient singly for immediate repetition. The materials from this experiment are listed in Appendix D.

2.2.4. Repetition and picture naming for words varying in position of syllabic stress

The final component was designed to assess the impact of a different phonological feature on the patients' success in word production, and its relationship to the pattern of past-tense verb production. In English, bi-syllabic words typically have stress on the initial syllable. The stimulus items were 24 words, all names of picturable objects, drawn from a test created by Nickels and Howard (1999). Half of the items had the typical pattern of initial stress, for example "rocket," and the other half had the atypical pattern of second-syllable stress, for example "balloon." The two sets were matched for frequency. Object names were selected as stimulus items so that the impact of stress position on word production could be assessed in both repetition and picture-naming tasks. A random order of the 24 items was presented (on different occasions) to each patient in each of the tasks.

3. Results

3.1. Past-tense production

3.1.1. Accuracy

The individual patients' rates of correct responses in producing regular and irregular past-tense forms in each of the three production tasks are displayed in the first six columns of Table 4. The table also presents each patient's average success on regular and irregular items across the three tasks (columns 7 and 8) and the discrepancy between these (column 9). The final column (10) gives each patient's overall irregular–regular discrepancy as a proportion of his or her average performance on both verb types in all three tasks; this is because, although score pairs of 90% vs. 75% and 40% vs. 25% both differ by 15%, they do not seem like identical outcomes. This issue becomes of greater importance when we wish to ask how the degree of advantage for irregular verbs correlates with another difference such as the degree of advantage for repeating monomorphemic words without consonant clusters. Before being entered into such correlations, therefore, the measures on all experimental tasks were converted to proportions of the patient's average performance on the same task. Table 4 establishes that the patients varied considerably in the extent to which their overall performance (column 9, IRR–REG) revealed an advantage for the irregular > regular past tense. Furthermore, both specific patients and specific tasks differed in the consistency with which they demonstrated this pattern. The first four patients in Table 4 achieved higher scores on irregular verbs for all three tasks, whereas the remaining patients

Table 4
The first six columns give each patient's performance [% correct], plus means, on production of the regular and irregular past-tense verbs in the screening test, which included three different production tasks. Subsequent columns give means across the three tasks, the size of the advantage for irregular relative to regular in each patient's average performance across the three tasks, and the size of this advantage relative to the patient's overall success rate

	Generation		Repetition		Reading		Mean across three tasks		IRR–REG	Proportional
	REG	IRR	REG	IRR	REG	IRR	REG	IRR		
AB	25	33	67	79	17	42	36.3	51.3	15.0	0.34
GN	33	63	83	96	54	67	56.7	75.3	18.7	0.28
JL	71	83	67	100	83	100	73.7	94.3	20.7	0.25
GD	67	75	67	92	75	88	69.7	85.0	15.3	0.20
PG	54	29	71	83	38	75	54.3	62.3	8.0	0.14
DC	83	75	83	100	83	88	83.0	87.7	4.7	0.05
JS	75	54	79	96	50	46	68.0	65.3	−2.7	−0.04
DM	96	67	92	92	79	79	89.0	79.3	−9.7	−0.11
Mean	63.0	59.9	76.1	92.3	59.9	73.1	66.3	75.1	8.8	

did so on two, one or none of the tasks. Of the three tasks, repetition engendered the irregularity advantage most consistently (7/8 patients and no reversals). If one treats only differences of at least 5% points as suggesting an effect, the irregularity advantage surfaced for 4/8 patients in generation and for 5/8 in reading.

3.1.2. Errors

Table 5 categorises all of the different response types produced by the patients, as a group, in each of the three screening tasks. Proportion correct duplicates the information in Table 4, while the remaining categories correspond to different error types.

Reproducing the stem is an error that can only occur in the generation task. That is, although it is of course possible to produce the stem form in the other tasks, it is only in the generation task that the stem is included in the stimulus information, and thus where its production can appropriately be described as "reproduction." As Table 5 indicates, this was a reasonably common error for irregular verbs in the generation task, and an even more common one for regular verbs. This (non-significant) tendency for more stem errors to regular verbs can be explained by either theoretical position: a dual-mechanism account would presumably argue that these errors to regular verbs indicate failure of the mechanism for inflection-by-rule; our interpretation is that, in these unmatched sets, the regular past-tense forms are phonologically more complex than their irregular counterparts, and that—as the response becomes more challenging—the patients are more likely to resort to the default of reproducing the form that they have just heard.

"Morphological errors" in both repetition and reading, which were relatively rare, include production of the stem form and also any other morphological variant on the correct response, such as jumped → "jumping." In the generation task this error category refers to any morphological variant other than the stem form. These included some responses like "jumping" for both regular and irregular, but for irregular also included a number of regularisation errors: i.e., in place of an irregular past tense like "sold," a patient produced a regularised form "selled." A total of 9% of responses to irregular verbs in the generation task, i.e., slightly more than half of the morphological errors, were of this regularised form. Neither theoretical position would particularly predict such errors, but especially not the dual-mechanism account, since the rule-based mechanism is supposed to be malfunctioning in these patients. Such errors are almost certainly exacerbated by the inter-mixing of regular and irregular forms in the same test. A patient who has just managed to generate "shelled" as a correct response (in a sentence about shelling peanuts yesterday) might subsequently be more likely to generate "selled" as the past tense of "sell" than he or she would do under any other circumstances.

Phonological errors constitute the only other category of theoretical interest and with enough entries to warrant attention. These are responses whose phonological content had some identifiable overlap with the target word. There were very few such responses in the generation task, presumably because the stem form that the patient had just heard in the initial sentence provided such a prominent phonological model as to capture what might otherwise be a phonological error. There were also relatively few phonological errors in repeating the irregular past-tense verbs, but accuracy was so high in this condition that there could not be many errors of any kind. Repetition is the easiest task because the stimulus provides a precise model of the correct response; and, on our view, irregular past-tense forms are easier to repeat than regular past-tense forms because the irregulars are phonologically simpler (e.g., "ran" vs. "jumped"). The remaining three task conditions—repeating the regular past tense, and reading either the regular or irregular past-tense—all yielded more phonological errors than any other type of error, as we would expect from phonologically impaired patients. In the reading task, the excess of phonological errors to the regular past-tense exactly corresponds to the excess of correct responses to the irregular past-tense.

3.2. Delayed repetition

Table 6 displays results for individual patients plus means and standard deviations for the group as a whole on all of the item sets tested in both immediate and delayed repetition: regular/irregular past-tense verbs; words varying in frequency and imageability; and

Table 5
Mean proportions of correct responses and different types of errors on the three screening assessments

	Generation		Repetition		Reading	
	Regular	Irregular	Regular	Irregular	Regular	Irregular
Correct	0.63	0.60	0.76	0.92	0.60	0.73
Reproduce stem	0.24	0.17	—	—	—	—
Morphological error	0.03	0.14	0.02	0.00	0.06	0.06
Phonological error	0.04	0.03	0.20	0.08	0.28	0.15
No response	0.06	0.07	0.00	0.00	0.03	0.04
Other	0.01	0.00	0.02	0.00	0.03	0.03

Table 6
Each patient's success rate [% correct] in immediate and delayed repetition of various word and non-word stimulus sets, plus appropriate means across patients and tasks

	AB	GN	JL	GD	PG	DC	JS	DM	Mean	*SD*
Regular PT										
Immediate	85	82	91	97	97	100	94	100	93.3	6.8
Delayed	50	59	94	82	62	91	68	65	71.4	15.9
Irregular PT										
Immediate	97	94	91	97	94	97	88	91	93.6	3.4
Delayed	76	82	85	100	50	88	79	79	79.9	14.2
High Freq/High Imag										
Immediate	90	85	100	95	100	100	85	100	94.4	6.8
Delayed	75	90	90	100	90	100	75	95	89.4	9.8
High Freq/Low Imag										
Immediate	80	95	80	85	100	90	55	95	85.0	14.1
Delayed	65	85	60	85	80	85	45	85	73.8	15.3
Low Freq/High Imag										
Immediate	85	85	75	95	100	85	75	95	86.9	9.2
Delayed	70	80	65	90	75	85	75	90	78.8	9.2
Low Freq/Low Imag										
Immediate	85	70	65	100	80	90	50	85	78.1	15.8
Delayed	50	65	65	95	85	85	55	80	72.5	16.0
Non-words										
Immediate	40	60	63	85	56	60	46	54	58.0	13.4
Delayed	27	33	60	77	27	50	29	17	40.0	20.4
Mean all immediate	80.3	81.6	80.7	93.4	89.6	88.9	70.4	88.6	84.2	7.4
Mean all delayed	59.0	70.6	74.1	89.9	67.0	83.4	60.9	73.0	72.2	10.5
Mean immediate-delayed	21.3	11.0	6.6	3.6	22.6	5.4	9.6	15.6	11.9	7.2
Mean immed-del:AB, GN, JL, GD									10.6	
Mean immed-del:PG, DC, JS, DM									13.3	

non-words. Recall that, although we were predicting poorer performance for delayed than immediate repetition, the magnitude of this difference will almost certainly have been reduced by the fact that immediate repetition preceded delayed production on every trial, giving a significant boost to success in the delayed condition. Nevertheless, of the 56 individual comparisons between immediate and delayed repetition in Table 6 (8 patients × 7 different sets of items), there were only six small reversals (delayed > immediate, none of more than 5% points); and there were four cases of immediate = delayed. The remaining 46 comparisons were in the predicted direction of immediate > delayed, with the advantage for immediate varying from 3 to 44% points across patients and word sets. Although no control data were collected, normal individuals reproduce single words essentially flawlessly under these conditions (Murdock, 1961). As a whole, then, performance on this task in the current study confirmed impaired phonological working memory in the non-fluent aphasic patients.

With regard to the specific item sets: for the verbs, we predicted an effect of delay but not of regularity, as the regular and irregular past-tense forms of the verbs employed in this test were matched for phonological structure. The results fitted this prediction: a 2-factor ANOVA revealed a main effect of delay [$F(1,6) = 16.1$, $p = .005$] but no significant effect of regularity [$F(1,6) = 1.7$, $p = .23$]; the interaction between the two factors also did not reach significance [$F(1,6) = 3.6$, $p = .10$]. For the PALPA words, we predicted significant effects of delay, word frequency and word imageability, and all of these effects emerged in the analysis: delay [$F(1,6) = 9.3$, $p = .02$]; frequency [$F(1,6) = 8.3$, $p = .02$]; imageability [$F(1,6) = 15.9$, $p = .005$]. None of the three 2-way interactions, nor the 3-way interaction, reached significance (all F's $\leqslant 1$). Production of non-words is difficult for patients with phonological deficits under any conditions, and in line with this general principle, the eight patients tested here managed to repeat an average of only 58% of the non-words correctly even in the immediate condition, with a further drop to 40% correct after a delay [effect of delay $F(1,6) = 20.53$, $p = .004$].

In summary, these findings support the predictions regarding the general impact of delay on repetition (immediate > delayed) and the specific impact of word variables on repetition (regular = irregular past-tense verbs when the two sets are phonologically matched; high > low-frequency words; high > low-imageability words; words > non-words). By contrast, the degree of

Table 7
Each patient's performance [plus mean performance] in repeating the three sets of monomorphemic words varying in complexity at offset, onset, or both, plus the advantage for simple > complex in each set and—for the final set—this advantage measure as a proportion of overall success rate

	AB	GN	JL	GD	PG	DC	JS	DM	Mean	*SD*
Offset										
Simple	100.0	88.0	100.0	56.0	94.0	88.0	69.0	94.0	86.1	15.7
Complex	75.0	63.0	88.0	88.0	75.0	75.0	63.0	94.0	77.6	11.5
Simple–Complex	25.0	25.0	12.0	−32.0	19.0	13.0	6.0	0.0	8.5	
Onset										
Simple	94.0	75.0	94.0	81.0	100.0	100.0	75.0	88.0	88.4	10.3
Complex	75.0	75.0	81.0	69.0	50.0	88.0	75.0	75.0	73.5	11.0
Simple–Complex	19.0	0.0	13.0	12.0	50.0	12.0	0.0	13.0	14.9	
Both										
Simple	94.0	81.0	100.0	88.0	94.0	100.0	88.0	88.0	91.6	6.6
Complex	44.0	38.0	81.0	88.0	69.0	100.0	69.0	100.0	73.6	23.4
Simple–Complex	50.0	43.0	19.0	0.0	25.0	0.0	19.0	−12.0	18.0	
Proportional Simple–Complex	0.7	0.7	0.2	0.0	0.3	0.0	0.2	−0.1		

disturbance to phonological working memory (as measured by the magnitude of immediate > delayed) was not significantly associated with the extent to which these patients showed an irregularity advantage in past-tense verb production in our screening tests (unmatched materials). The two entries at the very bottom of the MEAN data column indicate the size of the immediate > delayed repetition advantage, over all stimulus sets, first for the four patients whose past-tense performance on the screening tests was characterised by a consistent irregular > regular pattern (JL, GN, AB, and GD) and then for the remaining four cases who did not show this pattern (PG, DC, JS, and DM). If anything, the harmful effect of a filled delay on repetition performance was slightly (though not reliably) greater in the second subset of patients than the first.

3.3. Complexity

Table 7 presents the results of the repetition tasks in which we manipulated phonological complexity of the stimulus words in the form of presence/absence of consonant clusters at the offset, onset, or both in monosyllabic, monomorphemic words. As indicated earlier, this manipulation was designed to mimic, as much as possible, the difference between (unmatched) sets of regular and irregular past-tense verbs: on average, the regular past-tense forms are more phonologically complex than the irregular (e.g., *walked* vs. *ran*, etc). Although this complexity difference in past-tense verbs reliably occurs at word offset, our account does not give special weight to offset. In English, the phonological combination of a long vowel or diphthong followed by a stop consonant followed by an alveolar stop (as at the end of a word like "typed") (a) can only occur at word offset, (b) only occurs in regular past-tense verb forms (Burzio, 2002), and (c) might be especially difficult to articulate; but apart from this special case, one might, if anything, expect complexity at onset to be slightly more of a problem for non-fluent aphasic patients who often have some difficulty with initiating articulation. In general, however, our prediction is that increased complexity at any position in a word will harm such patients' word production, and the more of it the worse the patients' performance will be (Braber et al., in press). As Table 7 demonstrates, the results support this prediction: for the patients as a group, words with consonant clusters at offset, onset or both yielded repetition performance that was, respectively, 8.5, 14.9, and 18% points worse than repetition of the closely matched words without such clusters. Of more importance for the goal of this study, there was a verging-on-significant correlation ($r = .69$, $p = .06$) between the size of the simple > complex advantage in the "Both" subset (as a proportion of average score on simple and complex for the same items) and the proportional size of the irregularity advantage in production of unmatched regular/irregular past-tense verbs. This relationship is demonstrated in Fig. 1, which indicates

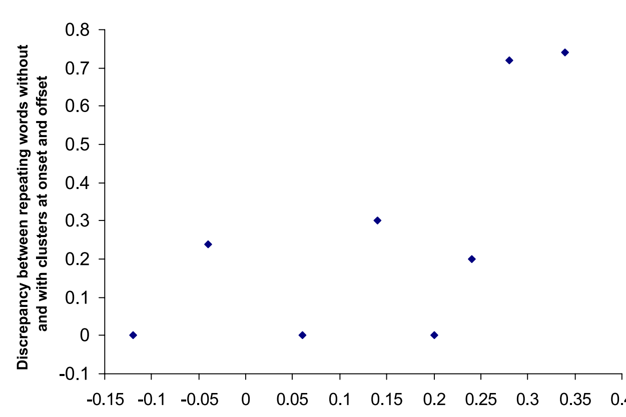

Fig. 1. The relationship, for each individual patient, of the discrepancy between irregular vs. regular past-tense production to the discrepancy between repeating monosyllabic words without vs. with consonant clusters at onset and offset. Both measures are scaled by (i.e., taken as proportions of) the patient's overall performance on the relevant task.

Table 8
Patients' accuracy for repetition and naming of bisyllabic words that vary in stress position

	AB	GN	JL	GD	PG	DC	JS	DM	Mean	*SD*
Repetition										
1st syllable stress	92.0	100.0	92.0	92.0	100.0	100.0	92.0	100.0	96.0	4.3
2nd syllable stress	42.0	58.0	83.0	100.0	92.0	92.0	92.0	75.0	79.3	20.0
1st–2nd	50.0	42.0	9.0	−8.0	8.0	8.0	0.0	25.0	16.8	20.4
Proportional 1st–2nd	0.7	0.5	0.1	−0.1	0.1	0.1	0.0	0.3		
Naming										
1st syllable stress	42.0	83.0	100.0	50.0	67.0	100.0	83.0	83.0	76.0	21.4
2nd syllable stress	8.0	17.0	67.0	8.0	42.0	75.0	58.0	58.0	41.6	27.2
1st–2nd	34.0	66.0	33.0	42.0	25.0	25.0	25.0	25.0	34.4	14.2
Proportional 1st–2nd	1.4	1.3	0.4	1.4	0.5	0.3	0.4	0.4		

that the correlation is carried mainly by two patients (GN and AB) whose success in repetition was strongly diminished when words had consonant clusters at both offset and onset (Table 7), and whose past-tense production was substantially better for irregular than regular verbs in our screening tests (Table 4).

3.4. Position of primary stress

Table 8 displays the patients' success when they were asked to produce—in spoken-word repetition on one occasion and in picture naming on another—the bi-syllabic object names that have stress on either the first or second syllable but are matched for frequency. As demonstrated by the "1st minus 2nd" scores, the group on average showed a reasonably strong advantage for words with 1st-syllable stress in repetition (with 6/8 individual patients' scores in the predicted direction), and an even stronger advantage in picture naming (with all 8 cases demonstrating the effect). The stress-position effect was marginally significant for repetition [$F(1,6) = 5.21$, $p = .06$] and highly reliable for naming [$F(1,6) = 31.2$, $p = .001$]. When the magnitudes of these discrepancies for each patient, as proportions of his or her overall scores on the corresponding task, were entered into correlations with the magnitudes of their discrepancies between irregular and regular past-tense verb production from our screening tests, the results were $r = .49$, $p = .22$ for repetition and $r = .71$, $p = .05$ for naming. Although these are not stunningly high correlations, and the former does not achieve statistical significance, recall that they are based on only 8 cases. The relationships are depicted in Figs. 2 and 3, which demonstrate that two patients for repetition and three for naming had a major advantage both for 1st- > 2nd-syllable stress and for irregular > regular past-tense verbs.

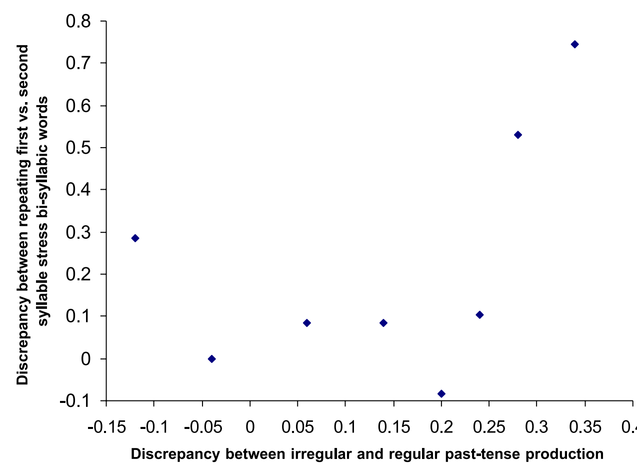

Fig. 2. The relationship, for each individual patient, of the discrepancy between irregular vs. regular past-tense production to the discrepancy between repeating bi-syllabic words with stress on the first vs. second syllable. Both measures are scaled by (i.e., taken as proportions of) the patient's overall performance on the relevant task.

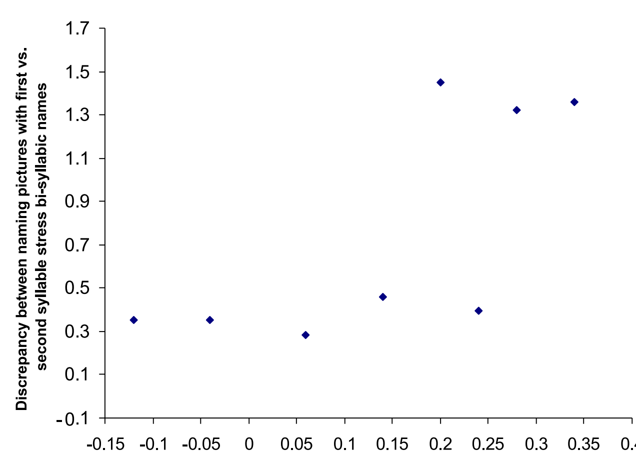

Fig. 3. The relationship, for each individual patient, of the discrepancy between irregular vs. regular past-tense production to the discrepancy between naming object pictures whose bi-syllabic names have stress on the first vs. second syllable. Both measures are scaled by (i.e., taken as proportions of) the patient's overall performance on the relevant task.

4. General discussion

The results of this study are intended to be viewed as part of a package with two previous studies by our research group (Bird et al., 2003; Braber et al., in press), all aimed at an attempt to understand the nature of the past-tense verb deficit in patients with non-fluent aphasia. The theoretical position guiding all of these studies (and indeed a further one on the nature of the past-tense verb deficit in patients with semantic deficits: Patterson et al., 2001) is as follows: for neuropsychological dissociations between regular and irregular past-tense verbs, as well as other forms of evidence regarding past-tense performance, a model based on a single integrated language system with distinctive phonological and semantic contributions (Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002) may provide a more promising account than a model of separate mechanisms for regular and irregular verbs (Pinker, 1999; Pinker & Ullman, 2002; Tyler, de Mornay Davies et al., 2002; Tyler, Randall et al., 2002).

In the initial study (Bird et al., 2003), 10 non-fluent patients—selected on the criterion of an advantage for irregular > regular past-tense verbs on a set of screening materials—no longer showed a significant difference when tested on pairs of regular and irregular past-tense forms matched for consonant–vowel phonological structure. Furthermore the patients, who were substantially impaired at classifying sequentially spoken stem and past-tense forms of regular verbs (like "press/pressed") as different, were equally impaired at judging the difference in non-morphologically related pairs like "chess/chest." Our interpretation of these results is that, although a component of the aphasic syndrome in such patients might be described as morphological (because the patients are generally impaired at past-tense production for both regular and irregular verbs), the apparent dissociation between regular and irregular past-tense forms is a by-product of the phonological characteristics of these two classes and can be explained by the patients' phonological deficits. The second study (Braber et al., in press) furthered the case for a phonological rather than a morphological interpretation of the irregular > regular pattern (in unmatched materials) by means of an extensive analysis of the errors made by the same 10 patients in producing past-tense verbs on a large set of stimulus materials (252 real verbs, half regular and half irregular, plus the same number of non-word pseudo-verbs). Setting aside the relative minority of trials where the patients were unable or unwilling to make any response, nearly all of the errors in the three production tasks (sentence completion, reading, and repetition) were close or distant phonological approximations to the target response—the criterion for this distinction being 50% phoneme overlap with the target. The balance between the proportions of close vs. distant errors was modulated by three factors: (a) the severity of the patient's aphasia, with the more severe patients producing a larger proportion of phonologically distant errors; (b) the difficulty of the task as measured by overall success rate, such that sentence completion (the hardest task) yielded the most phonologically distant errors, repetition (the easiest task) engendered the fewest of these far-off-target errors, and reading aloud fell between the other tasks in both overall success and proportion of distant errors; and (c) the difficulty of the stimulus materials (indexed by the impact of lexicality on general success rate), where the patients produced a higher proportion of phonologically distant errors on non-words than on words. Furthermore, the most typical phonological relationship between a target and its associated error response was that the response reduced complexity of the target. This analysis of the patients' performance in phonological terms leaves little if anything to be explained that would require an assumption of different processes for regular and irregular verbs.

The third, current study assessed eight non-fluent patients whose performance in producing past-tense forms in the three tasks on unmatched materials varied from an absolute advantage for irregular verbs of 20% (34% as a proportion of average success on both regular and irregular) to a disadvantage for irregular verbs of nearly −10% (−11% proportional to overall success). The goal this study was a first step in trying to identify the type of phonological deficit that leads to particular difficulty with regular past-tense forms in unmatched materials. That is: all non-fluent aphasic patients have some degree of phonological deficit; in order to make a convincing case for a phonological account of the irregular > regular pattern when it does emerge, we must be able to pinpoint, in phonological terms, some difference(s) between the patients who do and do not demonstrate this pattern. This point is underlined by Tyler, Randall et al. (2002) when they champion a dual-mechanism account of verb processing and challenge our phonological explanation of the irregular > regular pattern. The four non-fluent aphasics in their study had widely discrepant scores on tests of phonological ability. In a test requiring phonological segmentation of the initial sounds of words, for example, the percentages of correct responses for the four patients were 0, 29, 47, and 85, i.e., from complete failure to nearly normal. Importantly, however, these scores did not relate in any principled way to the patients' success on either of two receptive tasks involving regular past-tense verbs (primed lexical decision and same/different judgements to spoken words). It is perhaps worth noting that our own findings do not endorse this complete lack of correspondence. In Bird et al. (2003), only patient JL (out of 10) had essentially normal performance on a same/different receptive task almost identical to the one used by Tyler, Randall et al. (2002), and JL also achieved by far the highest scores on all phonological assessments (rhyme judgement, rhyme production, phonological segmentation, and blending); and patient RT, with the next highest accuracy in same/different judgements, was also relatively successful at phonological tasks (and the only patient other than JL with a perfect score at rhyme judgement). Nevertheless, we accept the challenge from Tyler et al. as an important one, not only because it is a generally valid point but also because—in the current study—success on phonological tasks like segmentation did not correlate significantly with the degree of the irregular > regular pattern in past-tense production on our screening materials.

So what did? Essentially two things: (1) a complexity effect, i.e., the degree of advantage shown by the various patients in repeating words without consonant clusters (e.g., the 3-phoneme word "lick") relative to matched words that included clusters at both onset and offset (e.g., the 5-phoneme word "blink"); and (2) a stress effect, i.e., the degree of advantage, in both immediate auditory-verbal repetition and picture naming, in producing object names that have syllabic stress on the first syllable relative to those with atypical second-syllable stress. There were coherent reasons for predicting an association between the impact of these two manipulations and the past-tense effect. The complexity effect is probably the most transparent: we have argued that the relative impairment in producing regular past-tense forms can be explained in terms of the extra phonological complexity that characterises these words relative to their irregular mates, and have bolstered this account by showing that the discrepancy between regular and irregular production can be eliminated when the items are matched for phonological structure. It therefore seems sensible that patients who show the irregular > regular discrepancy for unmatched verbs should also be the patients to suffer more from additional phonological complexity in producing morphologically simple words. Our reason for predicting the stress effect, which is a little less transparent, was as follows. Complexity at any point in a word might, and apparently does, cause difficulty for patients with an irregular > regular past-tense pattern. The particular form of phonological complexity that occurs in regular past-tense English verbs, however, is also a form of phonological atypicality, in the sense that the combination of phonemes at the ends of words like *typed* and *baked* does not occur in other contexts in English (Burzio, 2002). It therefore seems plausible that patients who demonstrate the verb discrepancy would be especially sensitive to other forms of phonological atypicality, of which position of syllabic stress is one.

A great deal clearly remains to be learned about the relationship between phonological and morphological processing. Our claim is that differences between success rates for regular and irregular past-tense verbs in non-fluent aphasia are attributable to phonological rather than morphological distinctions between the two verb types. Apart from a same/different receptive task on pairs of spoken words in Bird et al. (2003), however, this claim has been based entirely on tasks of speech production like the ones employed in this study. The alternative view held by Tyler, de Mornay Davies et al. (2002), Tyler, Randall et al. (2002)—that phonological differences may be important but that genuine morphological distinctions also play a vital role—has, by contrast, relied primarily on receptive tasks like primed auditory lexical decision. Furthermore, even where basic paradigms are similar, the attempt to compare (and explain discrepancies between) results supporting these alternative theories is hampered by differences in stimulus materials and details of experimental procedure. In light of all this, we do not claim that the present results resolve these issues; but they seem to take us at least one step further along the road. To summarise: the results demonstrate that, in a group of anterior aphasic patients, those with the largest and most consistent advantage for producing the past tense forms of irregular > regular English verbs were also the patients whose word production was most adversely affected by phonological complexity (in the form of consonant clusters at word onset/offset) and by phonological atypicality (in the form of syllabic stress on second rather than first position). In this regard, the results constitute another piece of our mosaic of evidence suggesting that the apparent morphological effect observed in some anterior aphasic patients is explicable in phonological terms.

Acknowledgments

This work was supported by a project grant from the Leverhulme Trust (F/00120/M) to MALR and KP, and by a National Institutes of Mental Health IBSC Grant (MH64445) headed by JLM. We are grateful to Katherine Ellis for assistance with data collection and to David Plaut and Mark Seidenberg for helpful discussions.

Appendix A. Past-tense verb forms for screening tests (from Bird et al., 2003)

	Regular	Irregular
1	stepped	fell
2	rocked	ate
3	passed	fought
4	spaced	led
5	marched	rose
6	heated	sat
7	wheeled	read
8	dusted	stood
9	voiced	spoke
10	tested	slept
11	cleared	cut

Appendix A (*continued*)

	Regular	Irregular
12	played	wrote
13	forked	wept
14	tempted	fled
15	grazed	ground
16	tuned	froze
17	tapped	leapt
18	roared	stung
19	dented	lent
20	laced	swam
21	raked	slit
22	chewed	strode
23	begged	stole
24	poured	tore

Appendix B. Past-tense verb forms for immediate and delayed repetition (from Bird et al., 2003)

	Regular	Irregular
1	seemed	meant
2	lived	kept
3	named	lent
4	tried	brought
5	guessed	cast
6	used	left
7	laid	won
8	showed	let
9	trained	ground
10	towed	bid
11	gained	bent
12	failed	sold
13	died	bought
14	pulled	built
15	filled	dealt
16	flowed	slid
17	viewed	fled
18	weighed	rode
19	called	held
20	sighed	shook
21	chewed	dug
22	sewed	rang
23	stewed	split
24	played	swung
25	sprayed	strode
26	paid	taught
27	dropped	slept
28	prayed	stole
29	cried	spoke
30	slapped	swept
31	wiped	wept
32	howled	wound
33	tied	bit
34	fried	froze

Appendix C. Non-words used for delayed repetition

1	diady
2	abius
3	nelass
4	vality
5	rummix
6	rillacy
7	firge
8	telpot
9	prifomil
10	ordon
11	arduter
12	laquist
13	narpolage
14	adermery
15	pannant
16	glush
17	exvipse
18	pastolity
19	norebom
20	ottiment
21	kelnet
22	newel
23	depper
24	wibster
25	intepus
26	offrabute
27	anderin
28	glitorion
29	logue
30	pomour
31	gintry
32	dackit
33	onimel
34	onalsion
35	quode
36	oren
37	vite
38	frid
39	bappy
40	shrint
41	suttertry
42	mecktace
43	rulap
44	putten
45	chistbut
46	intulince
47	biolan
48	finilver

Appendix D. Items varying in onset and/or final cluster complexity

Complex form	Frequency	Reduced form	Frequency
Items varying in onset and final cluster complexity			
blink	31	lick	22
clasp	35	lass	24
strand	146	and	132
glimpse	295	limp	191
twins	334	win	353
fleet	257	lee	308
brand	189	ban	199
cramp	42	cam	30
grunt	64	gut	98
clink	29	lick	22
glimpse	295	lip	304
blend	72	lead	445
stump	75	sum	568
crux	33	ruck	22
blunt	106	bun	67
strand	146	tan	107
Items varying in final cluster complexity			
paunch	29	pawn	34
scant	42	scan	20
scarf	142	scar	122
limp	191	lip	304
twins	334	twin	280
hint	281	hit	324
pence	132	pen	343
quilt	62	quill	26
wrench	52	wren	98
clamp	22	clam	14
brisk	148	brick	498
trunk	355	truck	444
shelf	246	shell	509
twitch	51	twit	14
swamp	78	swap	19
damp	482	dam	113
Items varying in onset cluster complexity			
stint	24	tint	25
thrift	25	rift	44
dread	142	red	141
spell	268	sell	259
slave	288	save	352
brush	243	rush	304
breach	167	beech	185
spike	35	pike	54
steal	59	eel	79
graft	22	aft	19
plump	225	lump	229
grain	466	gain	370
plot	345	pot	416
spill	25	sill	50
sting	71	sing	102
trim	113	rim	148

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