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Training grapheme to phoneme conversion in patients with oral reading and naming deficits: A model-based approach

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A model-based treatment focused on improving grapheme to phoneme conversion as well as phoneme to grapheme conversion was implemented to train oral reading skills in two patients with severe oral reading and naming deficits. Initial assessment based on current cognitive neuropsychological models of naming indicated a deficit in the phonological output lexicon and in grapheme to phoneme conversion. Using a single subject experimental design across subjects, the effects of treatment were evaluated by periodic probing of both trained and untrained regular words across lexical tasks: oral reading, oral naming, written naming, and writing to dictation. Results indicated successful acquisition of trained reading targets for both patients, as well as generalisation to untrained reading items, oral and written naming of trained items, and writing to dictation of trained and untrained items. Irregular words probed across the four lexical tasks did not demonstrate any improvement, as the trained grapheme to phoneme conversion skills were unsuccessful when applied to irregular words. The present experiment provides evidence for incorporating cognitive neuropsychological models in aiding the development of appropriate treatment protocols, and demonstrates the importance of rule-based learning, rather than compensatory strategies, in maximising the effects of generalisation.

INTRODUCTION

One popular model of lexical processing that describes single word comprehension and production is that proposed by Ellis and Young (1988; also Hillis & Caramazza, 1990; see Figure 1). In this model, the input to the semantic system consists of a heard word or a written word. The heard word or written word undergoes an initial peripheral featural analysis (accomplished by the auditory and visual analysis systems) followed by recognition as a familiar or unfamiliar word (which occurs in the visual and auditory input lexicons). To obtain the meaning of the recognised word, the semantic system needs to be activated, as the semantic system is the stored meaning representation of words. Of interest to the current experiment, from the semantic system there are two output mechanisms, the first being the phonological output lexicon, where the spoken word form is available to the speaker. The second mechanism, the graphemic output lexicon, functions as the written word form store and makes graphemic representations available for writing. The phonological output lexicon and the graphemic output lexicon are further connected to the phoneme level and grapheme level respectively, which are involved in sequencing of target phonemes or letters in the correct order. The model also specifies two conversion routes, the first being phoneme to grapheme conversion, which is

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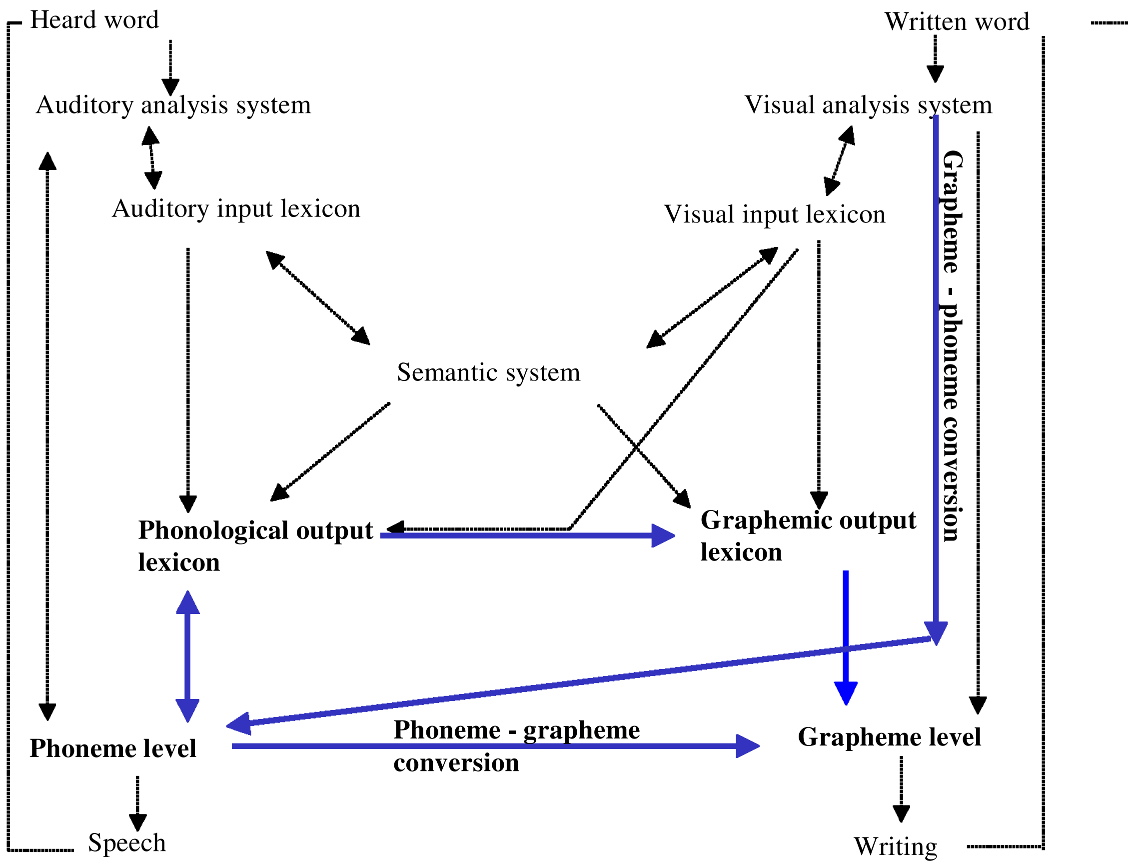

Figure 1. Model of single word production and recognition proposed by Ellis and Young (1988). Bold labels and lines indicate modules and connections of relevance to the present experiment.

involved in converting the sound sequence to a written word form. The second is called grapheme to phoneme conversion and is involved in converting the written word form into the corresponding sound sequence.

Use of the model has been proven beneficial in isolating impairments underlying oral reading and naming deficits in brain-damaged patients (Caramazza & Hillis, 1990; Caramazza & Miceli, 1990; Ellis, Miller, & Sin, 1983; Friedman & Kohn, 1990; Hillis, Rapp, & Caramazza, 1999; Miceli, Amitrano, Capasso, & Caramazza, 1996; Raymer, Thompson, Jacobs, & LeGrand, 1993). For example, numerous patients have been reported with oral reading and naming deficits that can be attributed to an impaired phonological output lexicon (Ellis et al. 1983; Miceli et al., 1996; Raymer et al., 1993). The model has also been used to guide treatment efforts (Bastiaanse, Bosje, & Fraansen, 1996; Raymer et al., 1993). Raymer et al. (1993) investigated the effects of training oral naming on oral reading and generalisation to untrained items in four patients. Treatment involved naming pictures using a hierarchy of cues: participants were instructed to name a picture; if unsuccessful, they were presented with a rhyming word, followed by an initial phoneme cue, and finally, if necessary an auditory model. Results indicated that all the four participants improved on oral naming of trained items, while three of the four participants improved on oral naming of untrained items. Two participants also improved on written naming of trained items. These findings indicated that model-based treatment may be successful in obtaining response generalisation.

Bastiaanse et al. (1996) report a case study investigating the effect of training grapheme to phoneme conversion skills in a patient with severe oral reading and naming deficits as a result of grapheme to phoneme conversion deficits. The treatment used was that described by Bachy-Langedock and de Partz (1989) and Nickels (1992). During treatment, the patient was first trained to learn grapheme to phoneme conversion which was then applied to non-words. During confrontation naming, the patient was required to write the initial graphemes of the target and use that as a self-phonemic cue. Significant improvements following treatment were noted on oral reading, oral naming, and letter sounding. However, no generalisation was noted on oral naming of untrained items. In addition, no improvements were noted on written naming and, as predicted, on two control tasks, namely spelling words to dictation and repetition of non-words.

Bastiaanse et al.'s case study is not the only existing report that has utilised the concept of training individual letters to improve oral reading skills. Nitzberg-Lott and colleagues (Nitzberg-Lott & Friedman, 1999; Nitzberg-Lott, Friedman, & Linebaugh, 1994) demonstrated that improving letter naming through tactile-kinaesthetic feedback resulted in improved oral reading skills on trained words as well as some generalisation to untrained words. Patients involved in these experiments demonstrated difficulty accessing the phonological word form of the written word through the semantic route and therefore relied entirely on the unimpaired grapheme to phoneme conversion route. Treatment involved a hierarchical tactile-kinaesthetic letter strategy, where patients were required to copy letters onto their palms with, and later without, cues. Results indicated that once patients were trained on the letter-by-letter reading strategy using tactile-kinaesthetic feedback, they were able to apply this rule to untrained letters and words as well.

It can be surmised from these studies that training individual letters and their spelling to sound correspondence should improve oral reading at the single word level. Based on Ellis and Young's model, this process would specify training the grapheme to phoneme conversion route to improve oral reading skills. It can be hypothesised that once the patient is able to convert graphemes to phonemes accurately, this ability can be applied to untrained words as well. Based on previous treatment experiments (Bastiaanse et al., 1996; Raymer et al., 1993), it can be hypothesised that improved oral reading skills will result in improved oral naming[1] skills. Of further interest is whether improved oral reading and naming skills result in improved written production skills, as the model suggests a direct link between the phonological and graphemic output lexicons. Under the theoretical assumption that these lexicons are modular, it is of interest if treatment such as the present experiment would facilitate access to the corresponding representations in different modalities.

The present experiment was aimed at developing a model-based treatment for patients with severe oral reading and naming deficits focused on maximising generalisation. The effects of training grapheme to phoneme conversion as well as phoneme to grapheme conversion in patients with severe oral reading and naming deficits were examined. Specifically, the experiment aimed to investigate if: (a) training grapheme to phoneme conversion would improve oral reading of trained words; (b) improvement in oral reading of trained words would result in generalisation to oral reading of untrained words; (c) improvement in oral reading of trained words would result in improvement of oral naming and written naming of the trained words; and (d) training phoneme to grapheme conversion would result in improved writing to dictation of trained and untrained words. As a result, the following specific predictions were made:

- *Oral reading.* According to the model, the phonological output lexicon contains the stored representation of the phonological form of the word. It was hypothesised that training grapheme to phoneme conversion of a target word would result in facilitating access to its phonological representation and, therefore, improvement in oral reading of the trained words was predicted. It was also hypothesised that once the patients were able to convert graphemes to phonemes successfully, this ability would be applicable to untrained words as well, thus, improvement in oral reading of the untrained words was predicted.
- *Oral naming.* It was predicted that the phonological representations accessed during oral reading of trained words were the same as those accessed during oral naming, and thus facilitating access to the phonological representations during oral reading would also improve oral naming of the trained words. However, as untrained words were not specifically targeted in treatment, their phonological representations were hypothesised to be less accessible than the trained words. Therefore, no generalisation or small generalisation effects were predicted for oral naming of untrained words.
- *Written naming.* It was predicted that training grapheme to phoneme conversion to facilitate access to phonological representations which would in turn facilitate access to corresponding representations in the graphemic output lexicon. It was predicted that as untrained words would not be influenced by treatment, the graphemic representations of these items might not be consistently accessible. Therefore, no generalisation effects were predicted for untrained words.
- *Writing to dictation.* It was predicted that training grapheme to phoneme conversion as well as phoneme to grapheme conversion would improve written spelling performance of both trained and untrained items. This is because, like oral reading, once the patients were able to convert phoneme to graphemes, this ability

[1] Oral naming here signifies oral confrontation naming, unlike some studies that refer to oral naming as oral reading.

would result in improved written spelling skills irrespective of whether the words were trained or not.

METHODS

Participants

Two monolingual, English-speaking, right-handed males aged 62 (RN) and 67 (RD) years, respectively, participated in the experiment. Each had experienced a unilateral left hemisphere cerebrovascular accident 13 and 27 months, respectively, prior to the experiment. Both patients presented with a lesion in the left temporoparietal region confirmed by a MRI or CT scan. RN was a physician with over 24 years of education, while RD was an engineer with over 20 years of education. Both patients had received general speech and language treatment following their stroke. However, this treatment was discontinued three months prior to their participation in the present experiment. As seen in Table 1, on the *Western Aphasia Battery* (WAB, Kertesz,1982), both RN and RD presented a pattern consistent with fluent conduction aphasia including fluent spontaneous speech, poor repetition, and poor naming. Performance on the *Boston Naming Test* (BNT, Goodglass, Kaplan, & Weintraub, 1983) revealed severe oral naming deficits for both patients.

In order to determine impairment at the level of the phonological output lexicon, portions of the *Psycholinguistic Assessment of Language Processing in Aphasia* (PALPA, Kay, Patterson, & Lesser, 1992) were administered. Based on testing, the overall pattern of impaired reading and naming performance was attributed to phonological output lexicon as well as grapheme to phoneme conversion impairment in both patients. Both RN and RD demonstrated good performances (70% or higher accuracy) on tests investigating (a) auditorily presented real word and non-word minimal pair discrimination, (b) visual letter reversal discrimination, (c) upper and lower case letter pair identification, (d) visual lexical decision of real words and non-words, (e) spoken letter to written letter matching, and (f) spoken/written word to picture matching. These findings were taken to indicate a relatively intact auditory analysis system, visual analysis system, visual input lexicon, and semantic system in both patients. Phoneme to grapheme conversion was not considered to be intact, as performance depended on task difficulty (see oral spelling).

Both RN and RD demonstrated impairments (50% or lower accuracy) on tests investigating (a) oral reading of words varied by syllable length, (b) oral reading of words varied by letter length, (c) oral reading of regular and irregular words, (d) oral reading of non-words, (e) oral spelling of non-words, (f) written confrontation naming, and (g) writing to dictation. In addition to the aforementioned tests, RN also demonstrated impairments in letter naming and letter sounding. RD demonstrated additional impairments in repetition of real words and non-words and oral spelling of real words. Although these patients presented with relatively intact semantic systems, they were unable to utilise the whole word semantic route as a successful strategy (unlike phonological alexics) as they performed poorly on oral reading of irregular words as well. Results of BNT and PALPA taken together indicated a primary locus of impairment at the level of the phonological output lexicon and in grapheme to phoneme conversion (albeit more severely for RN) in both patients. Concomitant deficits were noted for both patients at the level of the graphemic output lexicon and in phoneme to grapheme conversion. RD's performance on repetition of real words and non-words indicated additional impairments at the phoneme level as well.

TABLE 1
Scores from WAB, BNT, and PALPA before and after treatment

	RN		*RD*	
	Pre	*Post*	*Pre*	*Post*
Western Aphasia Battery (AQ)	*46.9*	*61.8*	*46.4*	*50.6*
Spontaneous speech	13	14	13	13
Auditory comprehension	6.35	7	7.7	8.5
Repetition	2.4	6.4	1.3	1.8
Naming	1.7	3.7	1.2	2
Boston Naming Test				
Number correct without cues	8%	17.6%	0	20%
PALPA: Auditory Processing				
Non-word minimal pair discrimination	85%	100%	95%	80%
Real word minimal pair discrimination	95%	98%	90%	100%
Repetition: Non-words	70%	83.3%	0%	0%
Repetition: Words	97.5%	90%	0%	45%
PALPA: Reading and Spelling				
Letter discrimination: Reversal	97%	100%	100%	100%
Upper case–lower case letter matching	85%	96%	100%	96%
Lower case–upper case letter matching	88%	96%	100%	96%
Letter naming	0%	77%	57%	92%
Letter sounding	38%	73%	69%	88%
Spoken letter–written letter matching	88%	100%	73%	88%
Visual lexical decision: Real words	80%	90%	90%	80%
Visual lexical decision: Non-words	100%	100%	100%	100%
Oral reading: Syllable length	0%	29%	33%	61%
Oral reading: Letter length	42%	42%	33%	75%
Oral reading: Regular and irregular words	0%	37.5%	8%	65%
Oral reading: Non-words	0%	0%	43%	54%
Oral spelling: Real words	55%	63%	0%	0%
Oral spelling: Non-words	0%	25%	0%	0%
PALPA: Picture and Word Semantics				
Spoken word–picture matching	100%	100%	98%	98%
Written word–picture matching	100%	100%	100%	98%
PALPA: Writing				
Written confrontation naming	0%	20%	20%	23%
Writing to dictation	4%	32.5%	10%	30%
Copying letters and words	100%	100%	100%	100%

Experimental stimuli

Prior to the experiment, both participants were presented with 50 single regular words and 20 single irregular words and were required to read the words and name their corresponding pictures. Feedback on this task was not provided. From the set of 50 regular words, 20 words that the participants could neither read nor name were selected for the experiment. These 20 words were picturable and ranging between high and mid frequency based on the Frances and Kucera (1982) written word frequency norms. As we selected words that the participants were unable to read, rather than proceeding with a pre-chosen set of stimuli, the words that were trained and tested during treatment differed for each individual. For each participant, the 20 words were randomly divided into two sets (trained and untrained) based on the following criteria: (a) the average frequency of occurrence of words in both lists was almost equal; (b) words in both lists were matched for the number of letters in the words; (c) no two words in a set belonged to the same semantic category; and (d) all pictures were equally imageable. Ten additional irregular words that the participants were unable to read/name were also selected to assess generalisation. See Appendix A for a list of stimuli used for each participant in the study.

For each participant, the 30 words were printed in large print (font = 18) on individual cards. For each of these words, corresponding black and white pictures that were approximately 5″ × 4″ in size were selected.

Design

A single subject experimental design across participants (Connell & Thompson, 1986; McReynolds & Kearns, 1983) was used to examine generalisation to untrained exemplars across tasks. As treatment was extended towards reading of 10 regular words, generalisation was tested on (a) oral reading of the untrained set of words, (b) oral naming of trained and untrained words, (c) written naming of trained and untrained words, and (d) writing to dictation of trained and untrained words. In addition, oral reading, oral naming, written naming, and written dictation of 10 irregular words were also assessed periodically throughout the study.

Baseline measures

Prior to treatment, each participant's reading, naming, and writing ability on all items was tested. All sessions were audiotaped for reliability purposes. The order of tasks was adjusted so that processes involved in the previous tasks would be least likely to influence performance on the following task. Therefore, oral naming was tested first followed by written naming, as neither orthographic nor phonological information is provided during these tasks. Writing to dictation was tested third, as no orthographic information is provided. Finally, oral reading was tested last, as access to the phonological information is aided by the orthographic information provided. Within each task the trained and untrained words were presented randomly. For oral naming, participants were instructed that they would be shown a picture and they should name it. For written naming, participants were required to write the name of the picture on a given response sheet. For written dictation, participants were instructed that they would hear a word and they should write the word on a separate response sheet. For oral reading, they were instructed to read word cards presented one at a time. A 20-second response time was provided following each stimulus presentation. If a response did not occur within the allotted 20-second period, a new stimulus was presented. Feedback as to accuracy of response was not given during baseline, however intermittent encouragement was provided.

All 80 regular stimuli (oral naming = 20, written naming = 20, writing to dictation = 20, oral reading = 20) were presented during each baseline session. Each session was approximately 1 hour in length. The 40 irregular words (10 = oral naming, 10 = written naming, 10 = written dictation, 10 = oral reading) were tested on one of the baseline sessions. The number of baseline sessions administered prior to application of treatment varied in a manner consistent with a multiple baseline design across participants. RN was tested on three separate occasions, whereas RD was tested on five separate occasions. All participant responses occurring during baseline testing were transcribed on-line by both the examiner and an independent reliability observer seated behind a one-way mirror.

Accurate responses that were produced for the target were marked as correct. A response was counted as correct only when (a) the response was clear, intelligible, and the target, (b) the participant initially produced close phonological approximations of the target and then achieved the target, or (c) the target was accurate but intelligibility was reduced due to exaggerated stress at the word end. Neologistic responses (e.g., *barnett* for *chicken*), semantic paraphasias (e.g., *sow* for *pig*, *hand* for *finger)*, circumlocutions (e.g., *it's round* for *wheel*), and phonemic paraphasias (e.g., *bradio* for *radio*) were all counted as incorrect responses. For written naming and writing to dictation tasks, a response was counted as correct only when the letters were clear and legible and all the letters of the word were accurate. One to three self-corrections were allowed.

Treatment protocol

Participants were trained to read words aloud through a series of steps that emphasised grapheme to phoneme conversion and phoneme to grapheme conversion. Treatment consisted of reading 10 regular words, none of which the participant could read/name during pretesting. Treatment steps for each word included: (a) oral reading of the word, (b) repetition of the word, (c) oral spelling of the word, (d) selection of the letters of the target word from distractors, (e) identification of target word letters presented randomly, and (f) reading the letters of the target word. Each trial began with presentation of a target word and the patient was asked to read it aloud. The training steps for that word were then initiated and on the final step, the patient was again presented with the target word for oral reading and feedback was provided. For the specific instructions that were used, see Appendix B.

Scrabble™ letter blocks were used for treatment steps that required manipulation of letters of the target word. These steps included selection of letters of the target word, identification of the target word presented randomly, and reading the target letters aloud. Distractors used with the target letters were selected prior to treatment and were based on the following criteria: (a) the number of distractor letters equalled the number of target letters (e.g., for the word *pig*, three distractor letters were used e.g., *d o k*); (b) at least one of the distractors was phonologically similar to a target letter (e.g., *k* for *g*); and (c) at least one of the distractors was orthographically similar to a target letter (e.g., *d* for *p*). The distractors were randomised before each treatment session such that no set of distractors for a target word was used consecutively. Accuracy on each of the nine steps on the treatment protocol (see Appendix B) was charted throughout the course of treatment.

Both participants were treated concurrently. Treatment was conducted once a day for 1 hour twice a week. A total of 36 treatment sessions were conducted for RN and a total of 30 treatment sessions were conducted for RD. As both patients were quite limited in their oral reading skills, a maximum of four items were practised during the beginning of treatment. By the end of treatment, all 10 items were practised within the 60-minute session. It is noteworthy that the patients were extremely motivated throughout treatment, even though both patients' performance on the eight treatment steps was relatively poor at the beginning of treatment. As treatment progressed, performance on the treatment steps improved.

Treatment probes

Throughout treatment, naming probes like those presented in the baseline were administered to assess performance on the various tasks. All the 20 items (10 trained and 10 untrained) were tested on oral reading, oral naming, written naming, and writing to dictation tasks after every three treatment sessions. Intermittent rather than consecutive probing was used in order to avoid potential access to the phonological word form during oral reading and writing to dictation tasks. The order of the tasks was kept consistent with baselines (oral naming, written naming, writing to dictation, and oral reading). Within each task, trained and untrained words were presented randomly.

Responses to these probes were coded and scored in the same way as in baselines, and served as the primary dependent measure in the study. Treatment was discontinued when oral reading of trained items was 90% accurate over two consecutive sessions. Generalisation to untrained items was considered to have occurred when levels of performance changed by at least 40% over baseline levels. At every fifth probe session, performance on oral reading, oral naming, writing to dictation, and written naming of irregular words was tested.

Post-treatment probes

Oral reading, oral naming, written naming, and writing to dictation of the trained and untrained regular words and irregular words were again assessed between 4 and 6 weeks following completion of the study. Procedures and analysis were identical to those used during baselines and treatment. At the end of the treatment, all the pretesting measures were administered to determine any changes following treatment.

Reliability

All the baseline and probe sessions were recorded on audiotape and 50% of the responses were also scored on-line by both the primary examiner and by an independent observer seated behind a one-way mirror. Point-to-point agreement between the primary examiner and the independent observer was greater than 95% across probe sessions. Daily scoring reliability checks by the independent observer were undertaken to ensure accurate presentation of the treatment protocol by the primary examiner. Point-to-point agreement ranged from 90–100%.

RESULTS

The data derived from the treatment probes during baseline and treatment phases of the study for both participants are illustrated in Figures 2–6 respectively. Shown in these figures are the percent correct named/read and written responses during baseline and probe sessions. Results indicated that experimental training resulted in improved oral reading of regular words, following stable baselines. Results for each task will be discussed separately.

Oral reading of trained and untrained items

As seen in Figure 2a, RN's baseline oral reading remained stable at 10% correct for all three baseline sessions. When treatment was applied to the training items, oral reading gradually improved from 10% accuracy during baseline sessions to 100% accuracy in treatment sessions. As seen in Figure 2b, RD's baseline oral reading ranged from 10–20% accuracy with a mean of 12% for trained items. Following initiation of treatment on the 10 treatment items, performance on these items increased from 20% accuracy during baseline sessions to 100% accuracy in treatment sessions.

For both RN and RD, as treatment was applied to the trained set, generalisation to the untrained set was noted. Reading accuracy of the untrained set improved from 20%

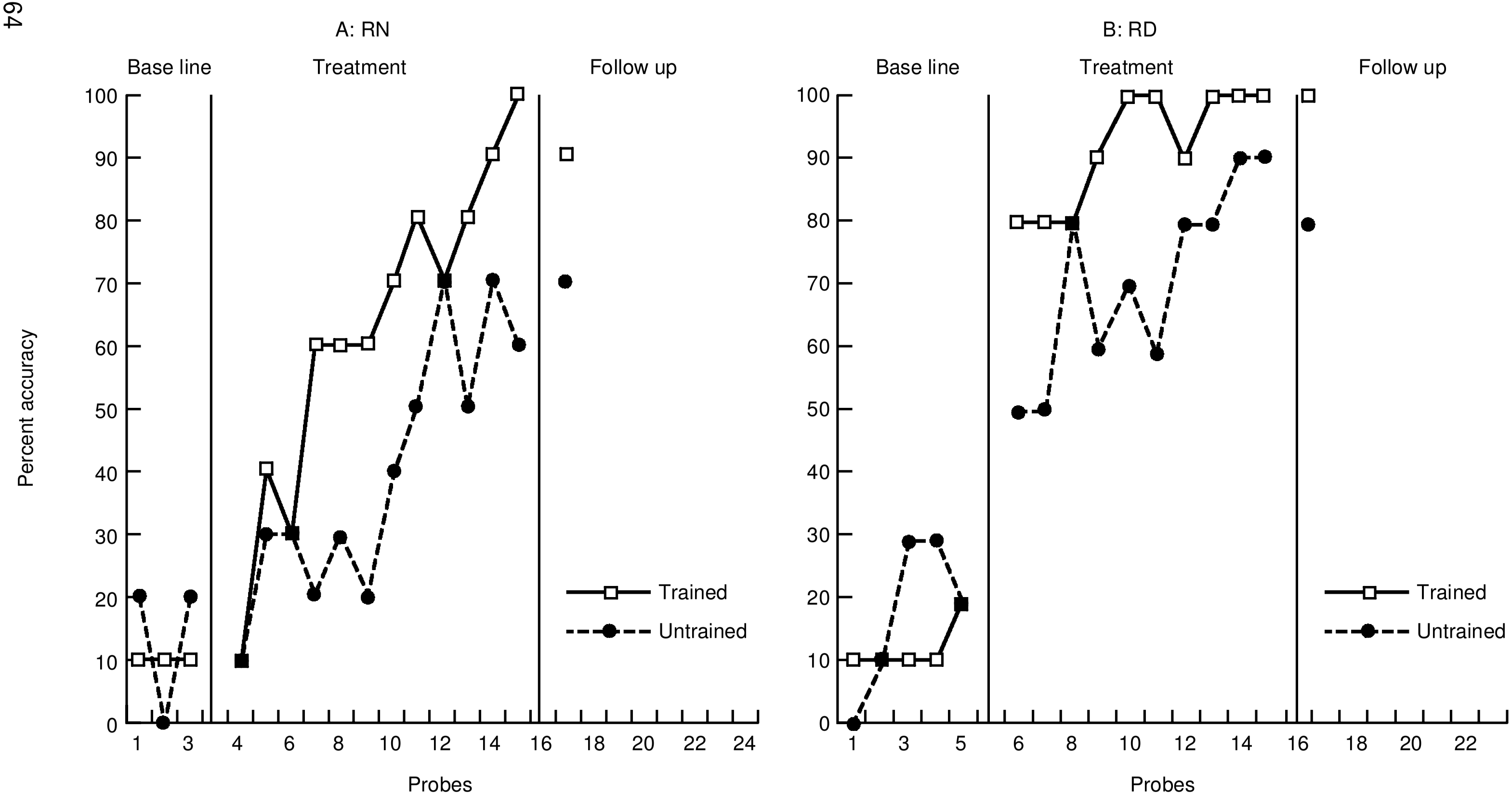

Figure 2. (a) Percent accuracy for acquisition of oral reading of trained and untrained words for RN. (b) Percent accuracy for acquisition of oral reading of trained and untrained words for RD.

accuracy during baseline sessions to 70% accuracy at the final treatment probe for RN, and from 30% accuracy during baseline sessions to 90% accuracy at the final treatment probe for RD.

Generalised oral naming

Once treatment was initiated on oral reading of trained items, oral naming of trained items also improved for both RN and RD. Naming accuracy for RN improved from 10% accuracy during baseline sessions to 80% accuracy following treatment on oral reading of these words. Similarly, naming accuracy for RD improved from 0% accuracy during baseline sessions to 70% accuracy (see Figure 3a and 3b). Improvements on oral naming of untrained items was also seen for both participants although not to the same degree as for trained items. RN improved from 20% accuracy during baseline sessions to 50% accuracy on oral naming of untrained words, while RD improved from 20% accuracy during baseline sessions to 60% accuracy on oral naming of untrained items.

Generalised written naming

For both RN and RD, treatment of oral reading resulted in improvements of written naming of trained words. For RN, performance on written naming ranged from 0% accuracy during baseline sessions to 80% accuracy at the final treatment probe, while for RD, performance on written naming improved from 30% accuracy during baseline to 90% accuracy (see Figure 4a and 4b). However, both patients demonstrated different performances on written naming of untrained items. For RN, little improvement in written naming of untrained items was noted, with performance ranging from 10% accuracy during baselines to 30% accuracy at the final treatment probe. RD, however, improved on written naming on untrained items through the course of the study, with performance at 70% accuracy on the final treatment probes. During baselines, however, RD demonstrated an increase in performance for written naming of both the trained and untrained items. Therefore, although he demonstrated the predicted generalisation patterns at least for the trained words, these results must be interpreted with caution as the baseline patterns are not completely clear.

Generalised writing to dictation

Treatment of oral reading of trained items resulted in generalisation to writing to dictation of trained and untrained items in both participants. For RN, writing to dictation of trained items improved from 10% accuracy during baseline sessions to 80% accuracy following treatment on oral reading of those items and for RD, writing to dictation of trained items improved from 30% accuracy during baseline sessions to 100% accuracy (see Figure 5a and 5b). In addition, both participants demonstrated improvements in writing to dictation of untrained words. RN improved from 0% accuracy during baseline sessions to 70% accuracy on writing to dictation of untrained words, while RD improved from 40% accuracy during baseline sessions to 80% accuracy on writing to dictation of untrained words.

Performance on irregular words

Performance on irregular words served as the control behaviour, as it was predicted that training grapheme to phoneme conversion would not result in any changes for irregular words. This is because grapheme to phoneme conversion cannot be applied to irregular

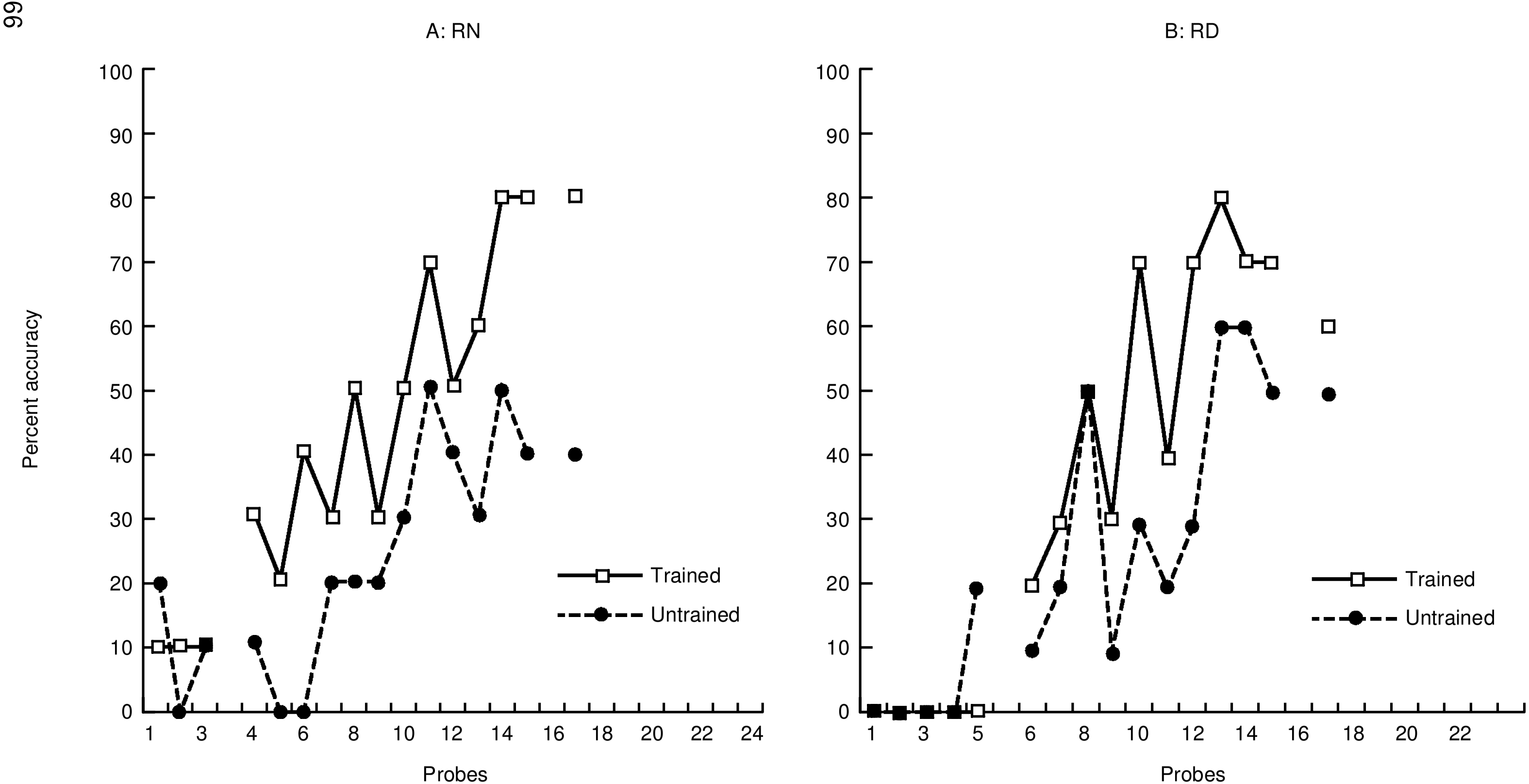

Figure 3. (a) Percent accuracy indicating generalisation of oral naming of trained and untrained words for RN. (b) Percent accuracy indicating generalisation of oral naming of trained and untrained words for RD.

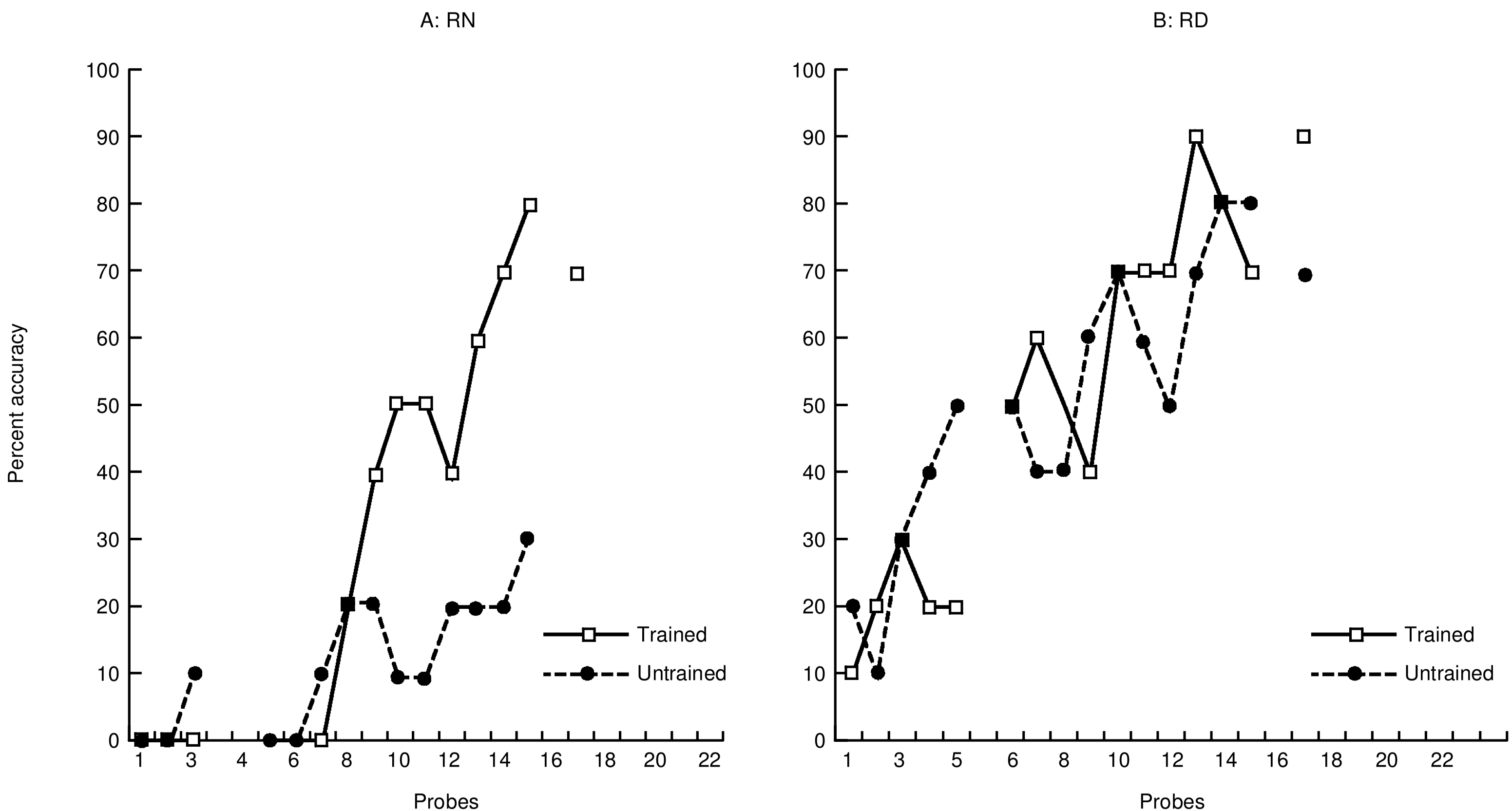

Figure 4. (a) Percent accuracy indicating generalisation of written naming of trained and untrained words for RN. (b) Percent accuracy indicating generalisation of written naming of trained and untrained words for RD.

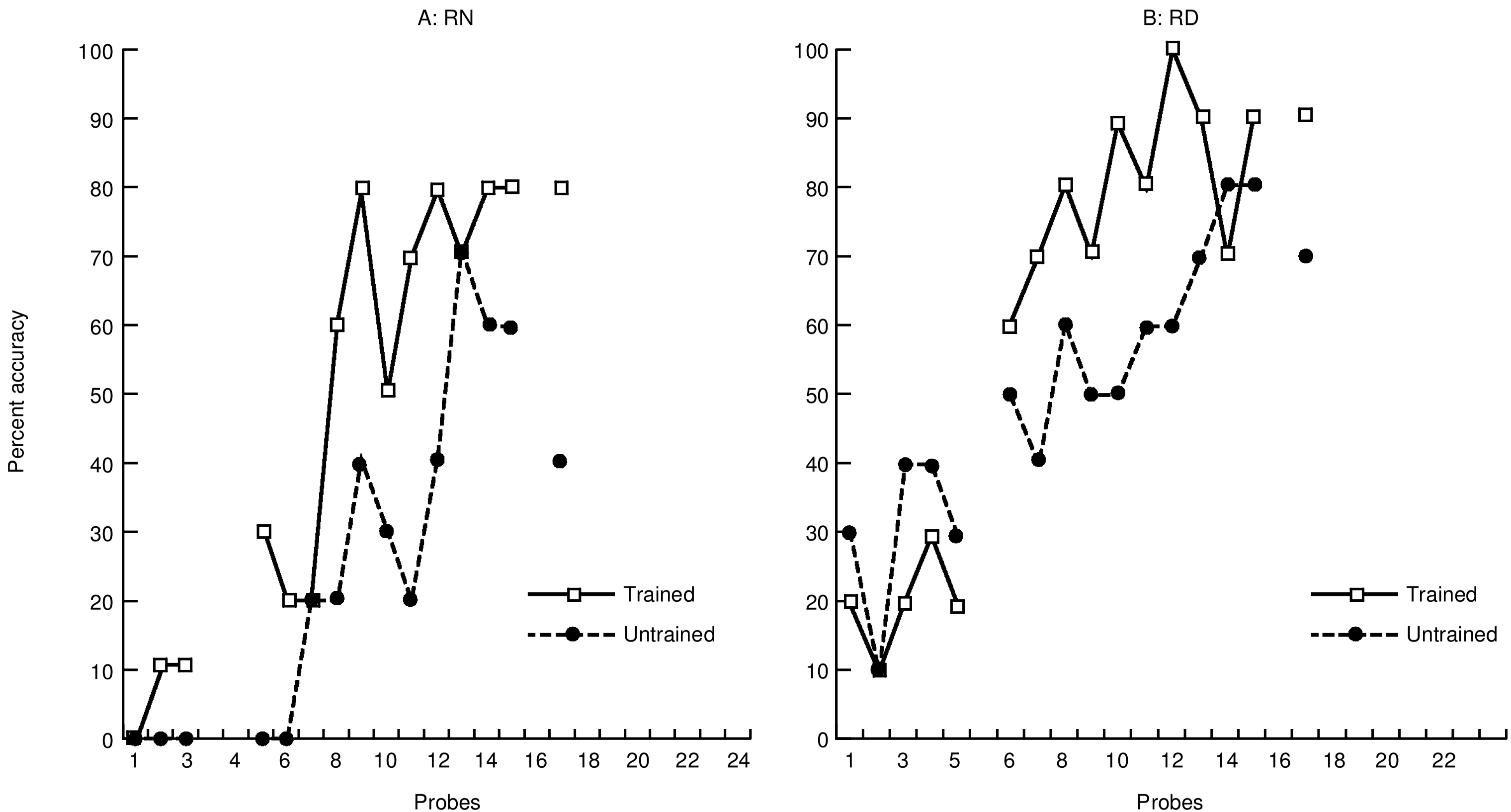

Figure 5. (a) Percent accuracy indicating generalisation of writing to dictation of trained and untrained words for RN. (b) Percent accuracy indicating generalisation of writing to dictation of trained and untrained words for RD.

words which, according to the model proposed by Ellis and Young, are accessed through the whole word semantic route. As predicted, treatment had little, if any effect, on irregular words on any task for either RN or RD (see Figure 6a and 6b).

Post-treatment probes

Results of post-treatment probe measures obtained for RN and RD are reported in Figures 2–6. For oral reading of trained items, performance was maintained at levels comparable to treatment levels in both participants. Generalised oral reading, oral naming, writing to dictation, and written naming were also maintained at levels comparable to treatment levels in both participants. In addition, for irregular words, performance on the four behaviours did not change remarkably during post-treatment probes.

Performance on aphasia test batteries

Pre-treatment and post-treatment performances on WAB (Kertesz, 1982), BNT (Goodglass et al., 1983), and PALPA (Kay et al., 1992) are shown in Table 1. Improvements were noted on WAB Aphasia Quotient as well as naming test scores on the WAB and BNT. Of greater interest, however, are the improvements noted in the PALPA subtests examining reading and writing. Both participants demonstrated improvements in letter naming, with RN improving from 0% to 77% accuracy and RD improving from 57% to 92% accuracy. Similar improvements were observed in letter sounding, with RN improving from 38% to 72% accuracy and RD improving from 69% to 88% accuracy. All tasks examining oral reading improved, including reading of words that were varied by syllable length (RN: 0% to 29%, RD: 33% to 61%), number of letters (RD: 33% to 75%), as well as oral reading of regular words (RN: 0% to 37%, RD: 8% to 65%). All these tasks utilise grapheme to phoneme conversion skills, a process that was directly trained in the present experiment. Also noteworthy are improvements in tasks that required phoneme to grapheme conversion skills. RN improved from 88% to 100% accuracy and RD improved from 73% to 88% accuracy on spoken letter to written letter matching. Additionally, RN improved from 4% to 32% accuracy and RD improved from 10% to 30% accuracy on writing to dictation tasks.

DISCUSSION

The results of the present experiment demonstrate that training grapheme to phoneme conversion resulted in improvements on oral reading of trained and untrained items in both patients. Both participants also demonstrated generalisation to oral naming of trained items, indicating improved access to phonological representations of the trained words in the phonological output lexicon. Notably, both participants improved on writing to dictation of trained as well as untrained items (indicating generalisation of phoneme to grapheme conversion skills learned during treatment), as well as written naming of the trained items. No improvements were observed on irregular words on any of the four behaviours probed for either participant, which was predicted given that grapheme to phoneme conversion is inapplicable to irregular words. The results of the present experiment demonstrate that access to impaired representations can be facilitated through a model-based treatment.

Previous studies have utilised neuropsychological models to guide treatments for naming and reading deficits. Of these, Raymer et al. (1993) reported improvements on oral reading and written naming of trained items following training of oral naming.

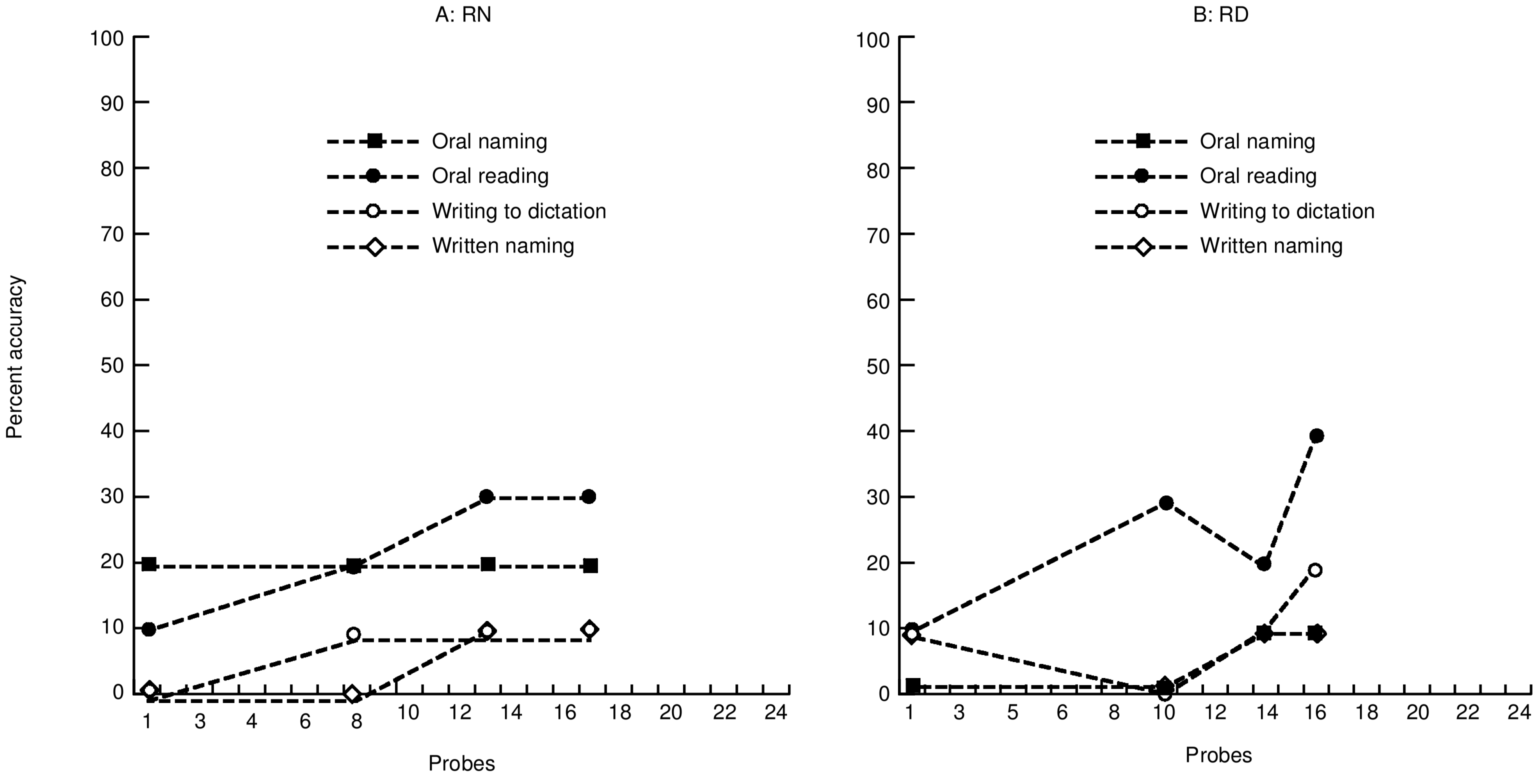

Figure 6. (a) Percent accuracy on oral reading, oral naming, written naming, and writing to dictation for irregular words for RN. (b) Percent accuracy on oral reading, oral naming, written naming, and writing to dictation for irregular words for RN.

Furthermore, Bastiaanse et al. (1996) demonstrated improvements on oral reading and naming in a patient following training of grapheme to phoneme conversion skills. The present experiment provides further evidence that model-based treatment, specifically training grapheme to phoneme conversion skills, results in improvements in oral reading skills as well as generalisation to oral and written naming of trained items. Furthermore, the present experiment provides preliminary evidence that training phoneme to grapheme conversion results in improved writing to dictation skills for both trained and untrained words.

We provide theoretical explanations for the improvements observed that are based on the model of single word comprehension and production. First, training grapheme to phoneme conversion during oral reading of 10 words resulted in generalisation to untrained words. Therefore, the ability to successfully convert graphemes to phonemes appears to have facilitated access to phonological representations of both trained and untrained words in the phonological output lexicon. These phonological representations may exist separately for each word or may be represented by interconnected microfeatures that are shared by different words (Coltheart & Byng, 1989). Consequently, although the model does not specify such a connection, we suggest a direct link between the grapheme to phoneme conversion route and the phonological output lexicon, as the ability to translate graphemes to phonemes can now be applied to both trained and untrained words (Buchanan, Hildebrandt, & MacKinnon, 1994; Shallice, Warrington, & McCarthy, 1983). Alternatively, we may have strengthened the feedback link between the phoneme level and the phonological output lexicon as, according to the model, the grapheme to phoneme conversion route activates the phoneme level which, through feedback, could activate the phonological output lexicon.

Our second observation was that training grapheme to phoneme conversion during oral reading resulted in improved oral naming of trained words. To explain the potential mechanism of this effect, we extend the hypothesis of the model proposed by Ellis and Young further to suggest that within the phonological output lexicon (and possibly other modules) there exists a critical threshold above which the word (or phonological form in this case) is considered to be activated. Although the notion of critical thresholds is similar to the premise of connectionist models (e.g., Dell, 1986), our data do not completely support connectionists models either, as according to these models, training skills such as grapheme to phoneme conversion should have no differential effect on regular and irregular words. Instead, our aim is to provide the most plausible explanation for the effects of our treatment.

Prior to treatment, during oral reading or naming of trained words, the phonological representations may have been below the critical threshold. Training grapheme to phoneme conversion (and phoneme to grapheme conversion) raised the phonological representations of these words above a critical threshold such that they could be accessed when presented with the written stimulus (i.e., during oral reading). Similarly, the raised thresholds of the trained words remained available for access when presented with a picture stimulus even though no orthographic information was available (i.e., during oral naming). For oral reading of untrained words, the patients were also successful at converting the presented graphemes to their corresponding phonemes, and as a result, the phonological representations were raised above the critical threshold for that task. However, during oral naming of untrained words, because no orthographic information was available to apply the learned grapheme to phoneme conversion rules, the thresholds of the phonological representations of these words may not have crossed the critical level to remain consistently available for access.

Based on these findings, it can be hypothesised that the same phonological representations are accessed during oral reading and oral naming with differing threshold levels, contrary to some recent suggestions (Breen & Warrington, 1994; Orpwood & Warrington, 1995). The findings of the present experiment corroborate suggestions that reading and naming rely on the same set of phonological representations, and that the apparent dissociation between the tasks is attributable to the intrinsic differences between the two tasks (Lambon-Ralph, Cipolotti, & Patterson, 1999). Naming receives only one input, semantic activation, whereas reading aloud is achieved by a combination (or summation, Hillis & Caramazza, 1995) of phonological activation derived from semantic as well as orthographic sources of activation. The results of the present experiment suggest that in patients who cannot utilise semantic or orthographic information effectively during oral reading and naming tasks, training grapheme to phoneme conversion skills could be an indirect route to improving access to semantic and phonological representations.

Training grapheme to phoneme conversion skills and facilitating access to phonological representations of trained words resulted in improved access to graphemic representations of trained words in the graphemic output lexicon as well. This finding is clear in RN, who demonstrated improvement from 0% during baseline to 80% accuracy in written naming of trained words. RD, however, demonstrated improving trends of both trained and untrained words during baseline. Therefore, although improvements were observed in both trained and untrained words following treatment, these effects may not be purely due to treatment. Nevertheless, the fact that both patients demonstrated improvements on written naming of the trained words allows us to suggest that the phonological representations improved through treatment are capable of activating their corresponding graphemic representations through the hypothesised link between the phonological output lexicon and graphemic output lexicon. Ellis and Young (1988) substantiate this hypothesis in their model, where they suggest that one of the inputs to the graphemic output lexicon includes the phonological output lexicon. During writing, the semantic representation of the word to be written is activated first, following which the activated phonological representation in the phonological output lexicon activates its corresponding representation in the graphemic output lexicon. Therefore, it is possible that in the present experiment, implicit activation of the strengthened phonological representations facilitated access to the graphemic representations for the trained words.

Furthermore, training phoneme to grapheme conversion skills as a part of treatment resulted in improved writing to dictation performance in both participants. This finding is especially notable, as during treatment the participants were only asked to orally spell the target word or their corresponding letters. At no stage were they required to write the letters on paper or even trace the letters with their fingers. Therefore, it appears that training phoneme to grapheme conversion improved access to graphemic representations that are common to both oral spelling as well as written spelling tasks. These representations can be located at the grapheme level (Ellis & Young, 1988) and can serve as input to the mechanisms computing specific letter shapes during written production or for letter name representations during oral spelling (Caramazza & Miceli, 1990). In other words, at the grapheme level, representations are a sequence of linear ordered strings that are common to both written spelling and oral spelling. The specific output form (whether upper/lower case letter or the name of a letter) required of the two different tasks is computed below this level. These findings present potential for future research because RN demonstrated a dissociation between oral spelling and written spelling, indicating normal performance on oral spelling but poor performance on written spelling. However, training oral phoneme to grapheme conversion in this patient resulted in improved written spelling skills.

Finally, the lack of improvements on irregular words confirms our prior predictions that improved grapheme to phoneme conversion and phoneme to grapheme conversion would be inapplicable to irregular words. Although irregular words were in general lower-frequency than the regular words used in treatment, these words were selected because they were quite familiar to the participants (*television*, *bicycle*, *knife*, *table*). We are reasonably certain that the lack of generalisation is not because of the lower frequency, but rather due to the inapplicability of the rules of grapheme to phoneme conversion.

As a final note, both patients demonstrated remarkable improvements on subtests of the PALPA that examined grapheme to phoneme conversion and phoneme to grapheme conversion. Also, according to anecdotal reports from the patients and their family members, the effects of treatment carried over to more functional everyday situations as well. For instance, following treatment, RN was able to read the newspaper headlines and prescription labels; RD was able to read street signs.

In conclusion, findings from this experiment indicate that grapheme to phoneme conversion treatment is useful in improving oral reading and oral naming skills. However, this treatment may be successful only in patients who present with oral reading deficits due to phonological output lexicon impairments and grapheme to phoneme conversion deficits. Therefore, for patients with phonological alexia (inability to use the grapheme to phoneme conversion route), this treatment may not be applicable because most often these patients can access the whole word semantic route fairly successfully. Similarly, patients with surface dyslexia cannot access the whole word semantic route, but are fairly adequate letter-by-letter readers. Potential for this treatment may exist for deep dyslexic patients, who are unable to convert graphemes to phonemes and rely on a somewhat impaired semantic system to read regular concrete words.

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APPENDIX A

Stimuli used for RN and RD

	Training	*Generalisation*	*Irregular words*
RN	Ship	Camera	Bread
	Wagon	Church	Table
	Radio	Tent	Telephone
	Piano	Tractor	Knife
	Finger	Towel	Elephant
	Clock	Ladder	Pear
	Belt	Bed	Bicycle
	Lamp	Wheel	Guitar
	Rabbit	Chicken	Puzzle
	Corn	Pot	Shoe
	Ave Frequency = 61.1	Ave Frequency = 84.1	Ave Frequency = 58
RD	Bus	Hat	Bread
	Ball	Towel	Table
	Pot	Bell	Television
	Hand	Camera	Knife
	Medal	Church	Onion
	Tent	Sun	Puzzle
	Pig	Wagon	Sword
	Card	Bottle	Bicycle
	Piano	Peas	Glove
	Ladder	Bed	Guitar
	Ave Frequency = 108.9	Ave Frequency = 100.8	Ave Frequency = 50.9

Note: Ave : Average

APPENDIX B

Treatment Protocol

1. From the training set, one word was presented and the participant was asked to read the word. If the participant was incorrect feedback was provided as follows '*Good try, but that wasn't quite right. Let's go through the training steps and I'll give you some help*'. If the participant was accurate, he was reinforced for his response and was proceeded to the next step.
2. The participant was asked to repeat the word after the examiner.
3. Following this, the participant was asked to spell the target aloud and feedback was provided. If the participant was unable to spell the word, the examiner spelled the word and asked the participant to repeat the spelling.
4. The examiner then presented the letters of the target word and equal number of distractors in a random sequence and the participant was asked to select the letters of the target word. If unable the select the accurate letters, the examiner selected the right letter for the participant with appropriate feedback '*Are you sure that is the correct letter? Let's go back and look for the right letter. Here is R*'. The examiner guided the participant through the remaining letters of the target word in a similar fashion. The participant was required to say the letters of the target word aloud as he was selecting them.
5. The examiner then presented each of the target letters in a random order to the participant who was required to identify the presented letter. If the participant was unable to identify the letter accurately, the examiner said the letter and asked the participant to repeat it. If no response was given, the examiner waited 10 seconds before providing the letter.

6. The examiner then formed the target word and participant was asked to read each letter aloud while pointing to the letter (e.g., *R*, point to *R*, *A*, point to *A*, *B*, point to *B*, *B*, point to *B*, *I T*). The participant was then required to read the entire word aloud. The examiner practised this step until the participant was able to read the letters and the word twice consecutively without cues from the examiner.
7. The examiner once again rearranged the letters with their distractors and the participant was required to construct the word as in steps 4 and 6.
8. The examiner finally presented the target word card for the participant to read aloud. Feedback was provided regarding accuracy. The examiner then proceeded to the next word.