APHASIOLOGY, 2005, 19 (1), 53–76

Psychology Press
Taylor & Francis Group

Training phoneme to grapheme conversion for patients with written and oral production deficits: A model-based approach

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Background: A previous study (Kiran, Thompson, & Hashimoto, 2001) investigated the effect of training sublexical conversion on improving oral reading of regular words in two individuals with aphasia. Results revealed that training grapheme to phoneme conversion improved acquisition of trained items and facilitated generalisation to trained and untrained stimuli during oral naming, written naming, and writing to dictation as well.

Aims: The aim of the present study was to extend this work to investigate if training phoneme to grapheme conversion would result in improvement of writing to dictation of trained items and facilitate generalisation to untrained stimuli and untrained tasks.

Methods & procedures: Using a single subject experimental design across three participants with aphasia, the effects of phoneme to grapheme conversion treatment were evaluated by periodic probing of both trained and untrained regular words across lexical tasks: writing to dictation, written naming, oral spelling, and oral naming.

Outcomes & Results: Results indicated that training phoneme to grapheme conversion resulted in improved writing to dictation of trained and untrained words in two out of three patients. In addition, improved written naming and oral spelling of trained words was observed. Marginal improvements were observed for untrained stimuli on written naming, oral spelling, and oral naming.

Conclusions: The results of this experiment demonstrate the effectiveness of training sublexical conversion to improve written production deficits and to facilitate generalisation to untrained stimuli and untrained tasks. These results also complement findings of our previous study to suggest a more efficient method of improving single word production deficits than training each modality successively.

A common observation in patients with aphasia is impairments involving oral naming, reading, and writing of single words. While the majority of research has been focused on oral production deficits (e.g., Goodglass, 1980), written production deficits have attracted increasing attention over the past few years (Beeson & Rapcsak, 2002; Rapp, 2002; Rapp & Beeson, 2003). A number of models have been proposed to explain single word comprehension and production in general (Ellis & Young, 1988, 1996); and written production in particular (Rapscak & Beeson, 2002; Rapp, 2002). According to the model proposed by Ellis and Young (1988, 1996), during oral naming or oral reading tasks, to

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The author wishes to thank JB, TW, and BH for their patience and cooperation throughout the experiment. The author also thanks Julie Tuchtenhagen, Caroline Spelman, and Alanna Plair for their assistance in collecting the data, and Belinda Fleming for analysing the written error patterns.

http://www.tandf.co.uk/journals/pp/02687038.html DOI:10.1080/02687030444000633

produce a target word (e.g., *cat*) information from the semantic system activates the spoken form */kæt/* in the phonological output lexicon (POL), which in turn activates the phoneme level (PL) in order to accurately sequence the target phoneme string. During written production tasks, the graphemic output lexicon (GOL) receives input from the semantic system and the phonological output lexicon in order to activate an abstract orthographic representation. To produce the written form in the correct letter sequence, the grapheme level (GL) is activated. Depending on whether the final output is spoken or written, the grapheme level assigns letter names or shapes respectively. The allograph level and graphomotor pattern level are located below the grapheme level and are involved in specifying the spatial representation of letters and the motoric execution movements for each letter, respectively.

There are also two conversion routes specified in the model. Phoneme to grapheme conversion (PGC) is involved in converting the sound sequence */kæt/* to a written word form *C A T* during spelling tasks. The second, called grapheme to phoneme conversion (GPC), is involved in converting the written word *CAT* form into the corresponding sound sequence */kæt/* during oral reading tasks. Use of the model has been proven to be beneficial in isolating selective impairments underlying oral reading, naming, and written deficits in brain-damaged patients (Beauvois & Derousné, 1981; Caramazza & Hillis, 1990; Caramazza & Miceli, 1990; Ellis, Miller, & Sin, 1983; Goodman-Shulman & Caramazza, 1987; Hillis, Rapp, & Caramazza, 1999; Rapp & Caramazza, 1997) and in guiding treatment methods for these deficits (De Partz, Seron, & Van der Linden, 1992; Miceli, Amitrano, Cappasso, & Caramazza, 1996; Raymer, Thompson, Jacobs, & LeGrand, 1993).

In a previous study (Kiran et al., 2001), the above-described model was utilised to train grapheme to phoneme conversion to improve oral reading in two patients with severe oral reading and naming deficits. Using a single subject experimental design across participants, the effects of treatment were evaluated by periodic probing of both trained and untrained regular words across lexical tasks: oral reading of a written word, oral naming of a picture stimulus, written naming of a picture stimulus, and writing to dictation of a heard word. Results indicated that training grapheme to phoneme conversion resulted in improved oral reading of both trained and untrained words in these patients. In addition, improved oral reading resulted in improved oral naming of the trained words, suggesting that the same spoken word representations were accessed during oral reading and oral naming. Moreover, improved spoken word representations during oral reading/naming facilitated access to written word representations during written naming of the trained items, indicating a strengthened connection between the phonological output lexicon and graphemic output lexicon for trained words. Finally, by incorporating a step of phoneme to grapheme conversion in treatment, both patients improved in their writing to dictation skills for trained and untrained words.

The present experiment was aimed at extending this work to train access to written words in patients with aphasia. Thus, the present research comprised part of a broader effort to demonstrate that reading, naming, and written tasks draw upon spoken and written representations that are mutually accessible, and that training representations in one modality facilitates access to representations in other modalities. While our previous work examined the effect of training grapheme to phoneme conversion on oral reading skills, the present experiment examined the effect of training phoneme to grapheme conversion on written skills.

Numerous studies have aimed at alleviating writing deficits in individuals with aphasia (see Beeson & Rapcsak, 2002, for a comprehensive review). Of these, several studies have focused on facilitating access to orthographic representations within the graphemic output lexicon (Aliminosa, McCloskey, Goodman-Shulman, & Sokol, 1993; Beeson, 1999; Berhmann, 1987; Berhmann & Byng, 1992; Carlomagno, Iavarone, & Colombo, 1994; De Partz et al., 1992; Hillis, 1989; Rapp & Kane, 2002; Raymer, Cudworth, & Haley, 2003; Seron, Deloche, Moulard, & Rouselle, 1980; Weekes & Coltheart, 1996). For instance, treatment programmes such as the Copy and Recall Treatment have been fairly successful at improving written word production across different types of patients with aphasia (Beeson, 1999; Beeson, Hirsch, & Rewega, 2002; Raymer et al., 2003). This treatment method emphasises a combination of semantic processing and copying words in order to memorise the spellings of words. Other studies that have examined the effectiveness of a specific treatment approach to facilitate a certain aspect of written production have focused on improving semantic access to written word forms (Hillis, 1991, 1992; Hillis & Caramazza, 1991; Raymer et al., 2003) or strengthening the graphemic buffer (Hillis, 1989; Hillis & Caramazza, 1987).

More relevant to the present investigation, several studies have aimed at improving the phoneme–grapheme conversion process (Carlomagno & Parlato, 1989; Carlomagno et al., 1994; De Partz, 1986; De Partz et al., 1992; Hatfield, 1983; Hillis & Caramazza, 1994, 1995; Hillis-Trupe, 1986; Luzatti, Colombo, Frustaci, & Vitolo, 2000). For instance, some studies have focused specifically on retraining spelling to sound correspondence rules using self-cueing strategies (Carlomagno & Parlato, 1989; De Partz et al., 1992; Hatfield, 1983; Hillis & Caramazza, 1994; Hillis-Trupe, 1986), while others have examined the effectiveness of multimodal spelling to sound correspondences (Carlomagno et al., 1994). Alternatively, Luzatti et al. (2000) have demonstrated improved oral spelling following simple segmentation of spoken words in two Italian patients with aphasia.

Therefore, while the notion of strengthening phoneme to grapheme conversion access in order to alleviate writing deficits is by no means a novel concept, the present experiment was aimed at developing a treatment programme based on phoneme to grapheme conversion that would be successful at facilitating improvements for both oral and written production deficits. Additionally, while some studies have previously demonstrated generalisation to untrained items (Rapp & Kane, 2002; Raymer et al., 2003), the aim of the present experiment was to demonstrate generalisation not only to untrained items on the trained task, but also to untrained items on untrained tasks. Specifically, this experiment aimed to investigate whether (a) training phoneme to grapheme conversions skills would result in acquisition of writing trained words to dictation, (b) improvement on trained words would result in generalisation to writing untrained words to dictation, (c) improvement in writing to dictation of trained words would result in generalisation to oral spelling of trained and untrained words, and (d) improvement in writing to dictation of trained words would result in generalisation to written naming and oral naming of trained and untrained words (see Figure 1). The following were the specific predictions:

- *Writing to dictation.* The present experiment was expected to replicate previous findings (Kiran et al., 2001) of improved writing to dictation of trained words following training of phoneme to grapheme conversion skills. It was also hypothesised that once the patients were able to convert phonemes to graphemes for trained words, this ability would be applicable to untrained words as well, thus improving writing to dictation of untrained words.

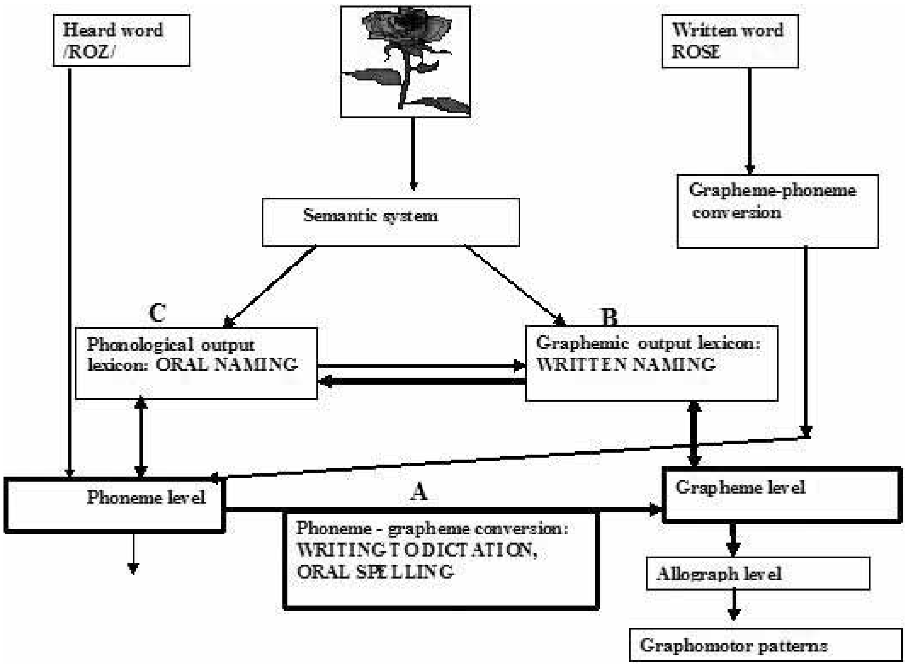

Figure 1. Schematic representation of single word comprehension and production adapted from Ellis and Young (1988, 1996). It was predicted that training phoneme to grapheme conversion would result in improved writing to dictation and oral spelling of trained and untrained items (A). Further, graphemic representations for written words were predicted to be available during written naming tasks as well (B). Finally, a bidirectional connection between written and oral naming was expected to facilitate improved oral naming of items (C).

- *Written naming.* It was predicted that the same graphemic representations would be accessed during writing to dictation and written naming. Therefore, facilitating access to written word representations during writing to dictation would simultaneously improve written naming of those words. Further, once patients were able to retrieve the untrained words during the writing to dictation task, these already active graphemic representations were hypothesised to be accessed subsequently during the written naming task.
- *Oral Spelling.* It was predicted that training phoneme to grapheme conversion would improve oral spelling performance of both trained and untrained items. This was because both writing to dictation and oral spelling involve the same process of phoneme to grapheme conversion, even though final output patterns differ for oral spelling and written spelling (Rapp, 2002).
- *Oral naming.* One of the predictions made by Ellis and Young (1988, 1996) was that spoken word forms in the phonological output lexicon were active during written word production. While our previous study demonstrated that improved oral reading and oral naming promoted access to written naming skills (Kiran et al., 2001), the present experiment extended this premise to contend that the connection between graphemic output and phonological output lexicon was bidirectional. Therefore, improved written production skills for trained items were expected to improve oral naming of trained items, since phonological representations were most likely also activated during treatment. However, phonological representations of untrained words

that were not directly targeted in treatment would not benefit in the same way, and thus were not predicted to improve.

Additionally, no generalisation was predicted on the four lexical tasks (writing to dictation, written naming, oral naming, and oral spelling) for a set of irregular words, which served as control items.

METHOD

Participants

Three monolingual, English-speaking male individuals with aphasia (age range = 59–67 years) characterised by written production deficits participated in the study. The participants were referred from regional speech pathologists and hospitals in the Austin area. Several participant selection criteria were met, including (a) a single left hemisphere stroke in the distribution of the middle cerebral artery confirmed by a CT/MRI scan, (b) onset of stroke at least 9 months prior to participation in the study, (c) at least a high-school degree (years of education range = 16–22 years). All participants had received varying amounts of traditional language treatment, which was discontinued at least 3 months prior to the present study. All participants also passed a puretone hearing screening at 40 dB HL bilaterally at 500, 1000, and 2000 Hz and showed no visual impairment as measured by the Snellen chart (see Table 1).

The diagnosis of aphasia was determined by administration of the *Western Aphasia Battery* (WAB, Kertesz, 1982) and other standardised language measures. Results showed that the participants presented with moderately fluent speech (range = 5–8), relatively intact comprehension (range = 6.95–10), varied oral naming skills (range = 3.9–7.1) and impaired written production skills (range = 3–7), although all were able to write their names and portions of the alphabet. All participants were able to comprehend written single words and phrases on the reading comprehension test of the *WAB*. All participants also showed impaired naming of high- and low-frequency items on the *Boston Naming Test* (BNT, Goodglass, Kaplan, & Wientraub, 1983; range = 11–66% accuracy; see Table 1).

In order to determine impairment in the graphemic output lexicon/grapheme level and in phoneme to grapheme conversion skills, subtests of the *Psycholinguistic Assessment of Language Processing in Aphasia* (PALPA, Kay, Lesser, & Coltheart, 1992) were administered. Results revealed that participants 1 and 2 were impaired on written naming (P1 = 0%, P2 = 0% accuracy) and writing to dictation (P1 = 5%, and P2 = 0% accuracy). Participant 3, in contrast, demonstrated mild impairments on writing to dictation (P3 = 80% accuracy) and moderate impairments on written naming (P3 = 67% accuracy). Likewise, participants 1 and 2 were impaired in matching spoken letters to written letters (P1 = 50%, P2 = 40% accuracy) while participant 3 was relatively adept at this task (P3 = 88% accuracy). However, all three were impaired at letter naming (range = 0–44% accuracy), letter sounding (range = 0–76% accuracy), oral spelling of real words (range = 0–5% accuracy), and oral spelling of nonwords (0% accuracy).

Participants varied on their performance on oral reading subtests of the *PALPA* (range = 55–95% accuracy). Additionally, all participants performed within normal limits on auditory and visual lexical decision tasks (range = 80–95% accuracy) and semantic processing tasks (range = 80–100% accuracy) indicating that the locus of impairment was not due to impaired visual processing or semantic processing. Participant 2, however, presented with additional impairments in phonological processing as shown by deficits in

TABLE 1
Demographic and stroke-related data for the three participants

	P1	*P2*	*P3*
Age (in years)	65	67	59
Handedness	Left	Left	Right
Years of education	18	16	22
Aetiology	L CVA	L CVA	L CVA
Years post onset	13	2	24
Western Aphasia Battery			
Spontaneous speech	13	12	18
Auditory comprehension	10	6.95	9.4
Repetition	8.6	5.8	7.2
Naming	3.9	5.7	7.1
Aphasia Quotient	**73**	**60.9**	**85.4**
Boston Naming Test (%)	11.7	36.7	66.7
PALPA			
Same–Different Word Minimal Pairs (%)	94.4	68.1	98.6
Lexical Decision: Imageability (%)	95.0	78.8	95.0
Nonword Repetition Task (%)	73.3	33.3	56.7
Letter Sounding (%)	0.0	0.0	76.9
Letter Naming (%)	26.9	0.0	44.2
Spoken letter to written letter matching (%)	50.0	50.0	88.5
Letter Length Reading (%)	70.8	70.8	91.7
Reading Task (%)	54.2	41.7	58.3
Spelling–Sound Regularity Reading Task (%)	63.3	40.0	55.0
Nonword Reading Task (%)	3.3	0.0	0.0
Regularity & Spelling (%)	0.0	0.0	0.0
Nonword Spelling Test (%)	0.0	0.0	0.0
Spoken Word–Picture Matching (%)	87.5	90.0	95.0
Written Word–Picture Matching (%)	85.7	80.0	100.0
Auditory Synonym Judgements (%)	86.7	76.7	85.0
Written Synonym Judgements (%)	81.7	46.7	83.3
Spoken Picture Naming (%)	35.0	75.0	62.5
Picture Naming: Writing Picture Names (%)	0.0	0.0	67.5
Picture Naming: Spelling Picture Names (%)	5.0	0.0	80.0

minimal pair judgements (68% accuracy), auditory lexical decision (78% accuracy), and nonword repetition (33% accuracy). Likewise, participant 3 presented with signs of deep dyslexia/agraphia characterised by semantic errors in reading (e.g., *knife/butter*), writing (e.g., *navy/sea*), and a superior performance on reading irregular words (60% accuracy) compared to regular words (50% accuracy).

Based on this testing, participant 1 was diagnosed with transcortical motor aphasia with concomitant impairments in the graphemic output lexicon/grapheme level, phoneme to grapheme conversion, and grapheme to phoneme conversion. Participant 2 was diagnosed with Broca's aphasia with concomitant impairments in the graphemic output lexicon/grapheme level, phoneme to grapheme conversion, and grapheme to phoneme conversion. Finally, participant 3 was diagnosed with anomic aphasia, deep dyslexia/agraphia characterised by concomitant impairments in phoneme to grapheme conversion and grapheme to phoneme conversion.

Stimuli

Prior to the experiment, all participants were presented with 50 single regular words and 20 single irregular words and were required to perform four tasks: writing to dictation, written naming, oral spelling, and oral naming. Feedback on this task was not provided. From the set of 50 regular words, 20 words that participants could not write, spell, or name were selected for the experiment. These 20 words were picturable and varied in frequency based on Frances and Kucera’s (1982) written word frequency norms. Since we selected words that participants were unable to write 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 divided into two sets (trained and untrained) based on the following criteria: (a) No difference in the average frequency of occurrence of words between trained and untrained sets—P1: $t(18) = 0.03$, $p > .05$; P2: $t(18) = -0.6$, $p > .05$, P3: $t(18) = -0.05$, $p > .05$. (b) Words in both lists were matched for the number of letters—P1: $t(18) = -0.86$, $p > .05$; P2: $t(18) = 0.49$, $p > .05$, P3: $t(18) = 0.34$, $p > .05$. (c) No two words were closely associated based on previous norms (see Edmonds & Kiran, 2004). (d) All pictures were equally imageable. Ten additional irregular words were selected with the above-mentioned criteria to serve as a control set. For each participant, the 30 words were printed in large print (font = 18) on individual cards. For each of these words, corresponding colour pictures that were approximately 5’’ $\times$ 4’’ in size were selected.

Design

A single subject experimental design (Connell & Thompson, 1986) with multiple baselines across subjects was employed. As treatment was extended towards writing to dictation of 10 regular words, generalisation was tested on (a) writing to dictation of the untrained set of words, (b) written naming of trained and untrained words, (c) oral spelling of trained and untrained words, and (d) oral naming 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 sessions

Prior to treatment, for each participant, performance on writing to dictation, written naming, oral naming, and oral spelling of the experimental stimuli (20 pictures and corresponding words) was assessed. All 80 trials (20 oral naming, 20 written naming, 20 oral spelling, 20 writing to dictation) were presented during each of the baseline sessions, which were approximately 2 hours in length. The 40 irregular trials (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. Participant 1 received three baseline sessions, participant 2 received five baseline sessions, and participant 3 received two baseline sessions.

The order of tasks was presented in such a manner that processes involved in the previous tasks would be least likely to influence performance in the following task. Therefore, oral naming was tested first followed by written naming, since neither orthographic nor phonological information is provided during these tasks. While phonological information was provided during the writing to dictation and oral spelling tasks, visualising the written letters as feedback during the writing to dictation task was expected to influence grapheme access during the oral spelling task. Hence, oral spelling was tested third and writing to dictation was tested last. Within each task, 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 oral spelling, participants were presented with a spoken word and were asked to provide the spelling for the word. For written dictation, participants were presented with a spoken word and were required to write the word on a separate response sheet. 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.

Accurate responses that were produced for the target were marked as correct. A response was counted as correct for the oral naming task 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 (e.g., *ribbit, rabbit*), or (c) the target was accurate but intelligibility was reduced due to exaggerated stress at the word end. For the written naming, oral spelling, and writing to dictation tasks, a response was counted as correct when (a) the letters were clear and intelligible, and (b) one letter was substituted (e.g., *hamder* for *hammer*), transposed (e.g., *slapter* for *stapler*), or omitted (e.g., *aspargus* for *asparagus*). This modification in scoring was incorporated to make the treatment motivating and functional for the participants as they were often satisfied with their response if only one letter was incorrect. One to three self-corrections were allowed. Incorrect responses on the two written tasks were further classified as (a) less than 50% correct letters spelled (e.g., *bakcdi/bookcase*), (b) more than 50% letters correctly spelled (e.g., *bookcseie/bookcase*), (c) picture of the target instead of letters, (d) semantic error that was incorrectly spelled (e.g., *kang/crown*), (e) semantic error that was correctly spelled (e.g., *king/crown*), (f) indiscernible or illegible letters, and (g) no responses. Responses were not analysed for oral spelling or oral naming as no significant trends in errors were predicted.

Treatment

Following baselines, the 20 stimuli were then divided into a trained (N = 10) and an untrained (N = 10) set. Each participant was trained to write to dictation 10 regular words through a series of steps that emphasised phoneme to grapheme conversion rules. Treatment steps for each word included: (a) writing to dictation of the word (involving phoneme to grapheme conversion), (b) copying the word, (c) oral reading of the word (grapheme to phoneme conversion), (d) selecting and writing the sounds of the target word from distractors in the accurate sequence (grapheme to phoneme to grapheme conversion), (e) writing phonemes of the target word presented auditorily but randomly (phoneme to grapheme conversion), and (f) writing to dictation of the word (phoneme to grapheme conversion). For the specific instructions that were used, see Appendix.

Scrabble™ letter blocks were used for treatment steps (# 4, 5, and 6) that required selection of and writing the sounds of the target word from distractors in the accurate sequence. Distractors used with the target letters were selected prior to treatment and were based on the following criteria: (a) 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.

Treatment for each participant was initiated at different stages in the experiment. Treatment was conducted once a day for 2 hours twice per week. A total of 20 treatment sessions were conducted for P1, 18 treatment sessions were conducted for P2, and 10 treatment sessions were conducted for P3. For both participants 1 and 3, there was a 2-week break in treatment coinciding with the holiday season. Also, both participants 2 and 3 became very frustrated with their inability to spontaneously access graphemes during the initial treatment sessions and were consequently provided with an alphabet sheet to facilitate letter access. This modification in protocol was not expected to confound the experiment in any way since (a) the alphabet sheet was present during both treatment and probe portions of the experiment, and (b) no feedback or cues regarding the alphabet sheet were provided by clinicians at any time during the experiment. Additional modifications were made in the treatment protocol for participant 2 who did not achieve criterion in treatment (see Results).

Treatment probes

Throughout treatment, acquisition of writing to dictation of 10 regular words and generalisation to writing to dictation of the untrained set of words, and written naming, oral spelling, and oral naming of trained and untrained words were tested weekly. Writing to dictation, written naming, oral naming, and oral spelling of irregular words were tested every fifth probe session. The order of the tasks was kept consistent with baselines (oral naming, written naming, oral spelling, and writing to dictation).

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 initiated following a stable baseline (less than 20% fluctuation in baseline) on the trained items. Treatment was discontinued when writing to dictation of trained items was 80% accurate over two consecutive sessions or 10 sessions elapsed with no improvement. Generalisation to untrained items was considered to have occurred when levels of performance changed by at least 40% over baseline levels. These criteria were similar to those followed in the Kiran et al. (2001) experiment.

Only participant 1 reached criterion on treatment acquisition. For participant 2, treatment was not effective in improving writing to dictation skills, thus after 10 consecutive treatment sessions, the treatment protocol was modified twice in order facilitate improvements. Participant 3 reached criterion for acquisition once during treatment; however, the timing of that performance coincided with a 2-week break, following which he ultimately only achieved 70% accuracy across two consecutive sessions. This participant developed certain health-related complications that precluded his ability to continue treatment; therefore, treatment was terminated at that point.

Post-treatment probes

At the end of the treatment, all the pretesting measures were administered to identify any changes following treatment. Follow-up treatment probes were not administered in this experiment, as participant 1 relocated following completion of treatment and participant 3 developed health problems.

Data analysis

The extent to which changes from baseline to treatment phases were statistically reliable was determined through a time series analysis using the C-statistic (Tryon, 1982). Further, errors produced during baselines and at the end of treatment were compared for each patient using a chi-square analysis.

Reliability

All the baseline and probe sessions were recorded on audiotape and 50% of the responses were also scored on-line by both the clinician and by an independent observer seated behind a one-way mirror. Point-to-point agreement 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 clinician. Point-to-point agreement ranged from 90% to 100%. Error analysis on the data was conducted by an independent researcher blind to the purposes of the study.

RESULTS

The data derived from the treatment probes during baseline and treatment phases of the study for three participants are illustrated in Figures 2–4 respectively. Shown in these figures are the percent correct named/spelled and written responses during baseline and probe sessions. Results for each task will be discussed for each participant.

Participant 1

Following three stable baselines, training phoneme to grapheme conversion skills resulted in improved acquisition of writing to dictation of trained items from 0% to 100% accuracy ($C = 0.916$, $z = 4.597$, $p = .001$; see Figure 2). Additionally, writing to dictation of untrained items also improved from 0% to 50% accuracy ($C = 0.705$, $z = 3.537$, $p = .001$). Likewise, generalisation to written naming of trained words (from 0% to 90% accuracy, $C = 0.889$, $z = 4.460$, $p = .001$) and untrained words (from 0% to 50% accuracy, $C = 0.763$, $z = 3.829$, $p = .001$) was observed for this participant. On the oral spelling task, participant 1 demonstrated generalisation only to the trained words (from 0% to 70% accuracy, $C = 0.909$, $z = 4.562$, $p = .001$). Generalisation to untrained words did not reach criterion (0% to 30% accuracy), although the trends were significant ($C = 0.790$, $z = 3.963$, $p = .001$).

Finally, participant 1's performance on the oral naming task was contradictory to prior hypothesis. This participant did not improve on oral naming of trained words (50% to 30% accuracy, $C = -0.053$, $z = -0.263$; $p = .604$), although improvements in oral naming of untrained words reached criterion (from 30% to 70% accuracy; $C = 0.423$, $z = 2.121$, $p < .05$). These findings suggest that at least in participant 1, oral naming of trained items was unaffected by treatment to improve written production skills. Performance on irregular words (which served as control) revealed no changes on oral spelling, writing to dictation, written naming or oral naming ($C = 0.485$, $z = 1.37$, $p = .085$; see Figure 5).

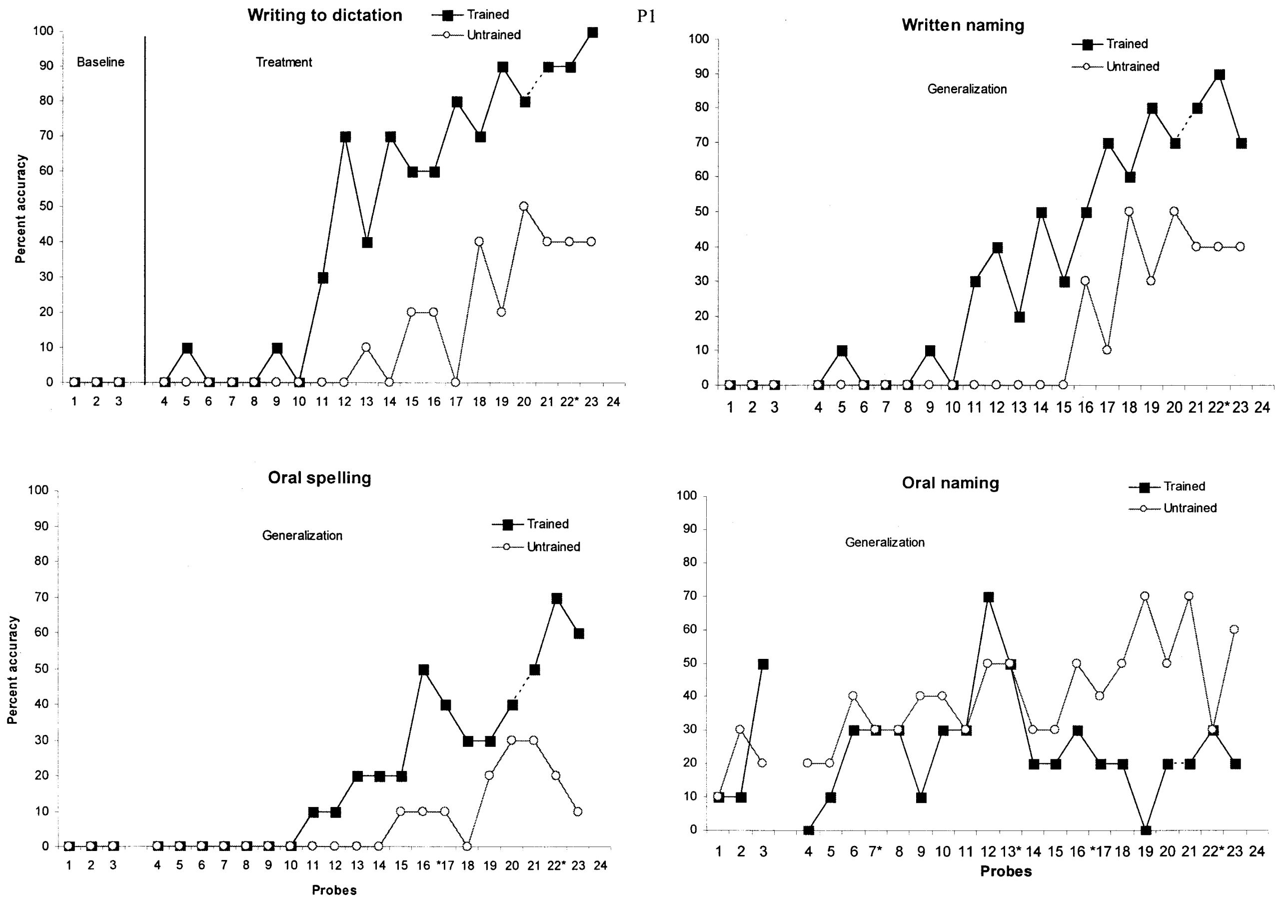

Figure 2. Percent accuracy on trained and untrained items on writing to dictation, written naming, oral spelling, and oral naming for participant 1. Dotted lines indicate a 2-week break in treatment.

Participant 2

Following 5 stable baseline sessions, participant 2 was trained on phoneme to grapheme conversion for 10 regular words. However, this participant did not improve on writing to dictation of trained items and therefore never achieved criterion (see Figure 3). Following 10 weeks of treatment, a modification in the treatment that entailed practising the alphabet at the beginning of every session was introduced, which also failed to facilitate writing to dictation of trained items. Following another 4 weeks, the treatment protocol was modified further to incorporate homework practice of trained words. This change in treatment was also unsuccessful in improving this participant writing to dictation skills and after 4 weeks, treatment was discontinued. The lack of effectiveness of training phoneme to grapheme conversion was apparent across writing to dictation, written naming, and oral spelling of trained and untrained words. Although oral naming also failed to reach criterion, significant statistical trends were observed for trained words ($C = 0.552$, $z = 2.771$, $p < .01$) and untrained words ($C = 0.683$, $z = 3.42$, $p < .001$).

On irregular words that were probed periodically, this participant demonstrated no changes on oral spelling, writing to dictation, and written naming; although oral naming appeared to improve (from 0% to 60% accuracy, $C = 0.47$, $z = 1.35$, $p > .05$, see Figure 5).

Participant 3

Following two stable baselines, participant 3 was trained on phoneme to grapheme conversion of 10 regular words. Improvements were noted rapidly on acquisition of trained items (from 0% to 80% accuracy; $C = 0.681$, $z = 2.577$, $p = .005$) (see Figure 4). Following two consecutive sessions of 70% accuracy on the trained items, treatment was discontinued for this participant since he developed a health problem that limited his ability to continue language treatment.

In addition to acquisition of trained items, participant 3 also demonstrated generalisation to writing to dictation of untrained items (from 0% to 70% accuracy, $C = 0.811$, $z = 3.068$, $p = .001$), written naming of trained items (from 0% to 70% accuracy, $C = 0.737$, $z = 2.788$, $p = .002$), and untrained items (from 0% to 50% accuracy, $C = 0.540$, $z = 2.044$, $p < .05$). Furthermore, improvements were observed on oral spelling of trained items (from 0% to 70% accuracy, $C = 0.631$, $z = 2.387$, $p = .008$) and untrained items (from 0% to 70% accuracy, $C = 0.631$, $z = 2.38$, $p < .01$). Oral naming of trained items also improved above criterion (from 0% to 70% accuracy) although this effect was not significant ($C = 0.353$, $z = 1.338$, $p = .090$), whereas oral naming of untrained items did not achieve criterion (from 0% to 30% accuracy) even though a significant trend was observed ($C = 0.718$, $z = 2.71$, $p < .01$). Finally, as mentioned before, this patient presented with superior ability to access irregular words compared to regular words (consistent with deep alexia/dysgraphia), therefore, presented with relatively adequate performance levels on writing to dictation (75%), oral naming (90%), and written naming (75%) of irregular words prior to initiation of treatment which did not change during the course of treatment. Performance on oral spelling of irregular words, however, changed as a function of treatment although not significantly (from 20% to 60% accuracy; $C = -0.54$, $z = 1.154$, $p > .05$).

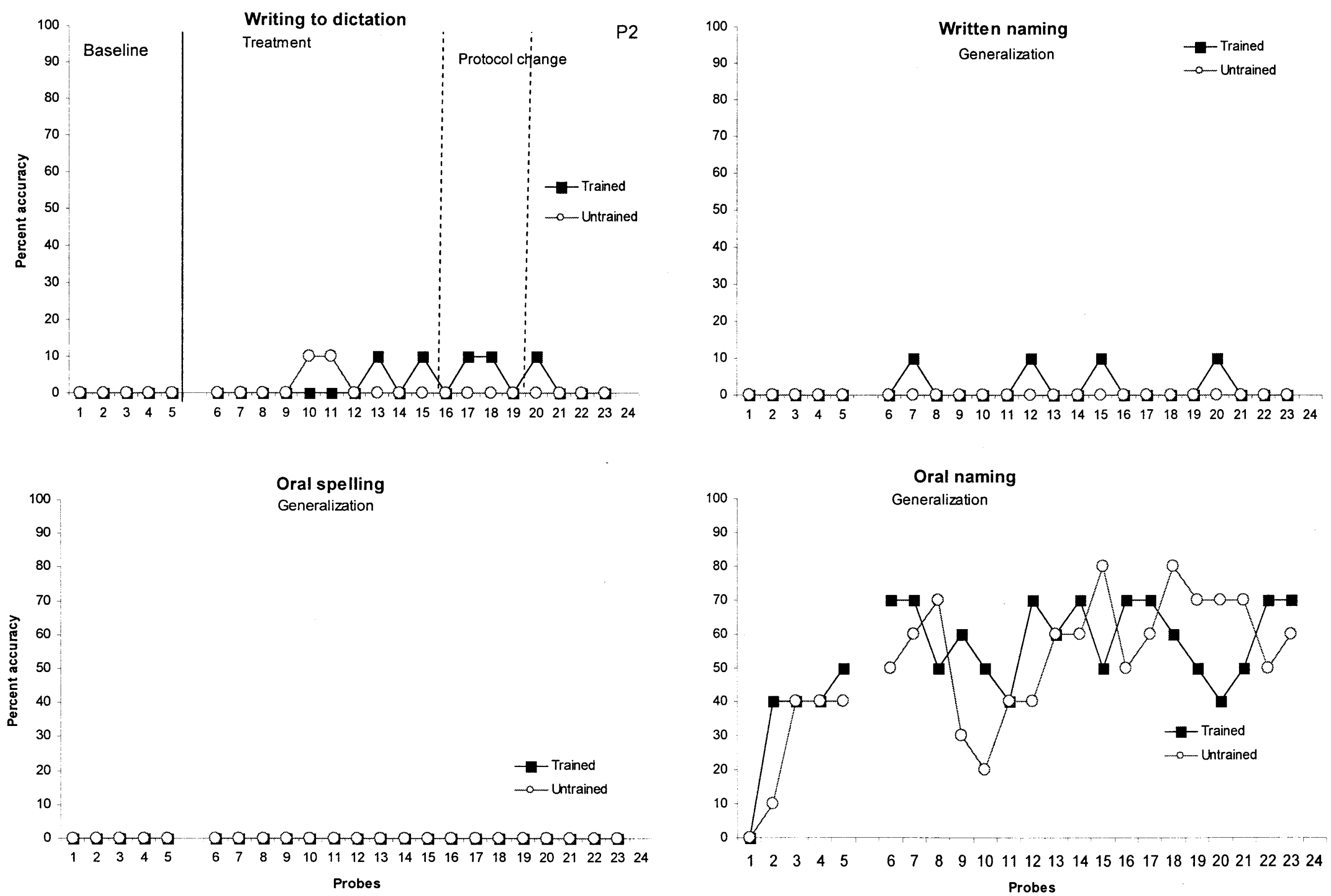

Figure 3. Percent accuracy on acquisition of trained writing to dictation and generalisation to untrained writing to dictation, trained and untrained written naming, oral spelling, and oral naming for participant 2. Change in treatment protocol illustrated by vertical dotted lines.

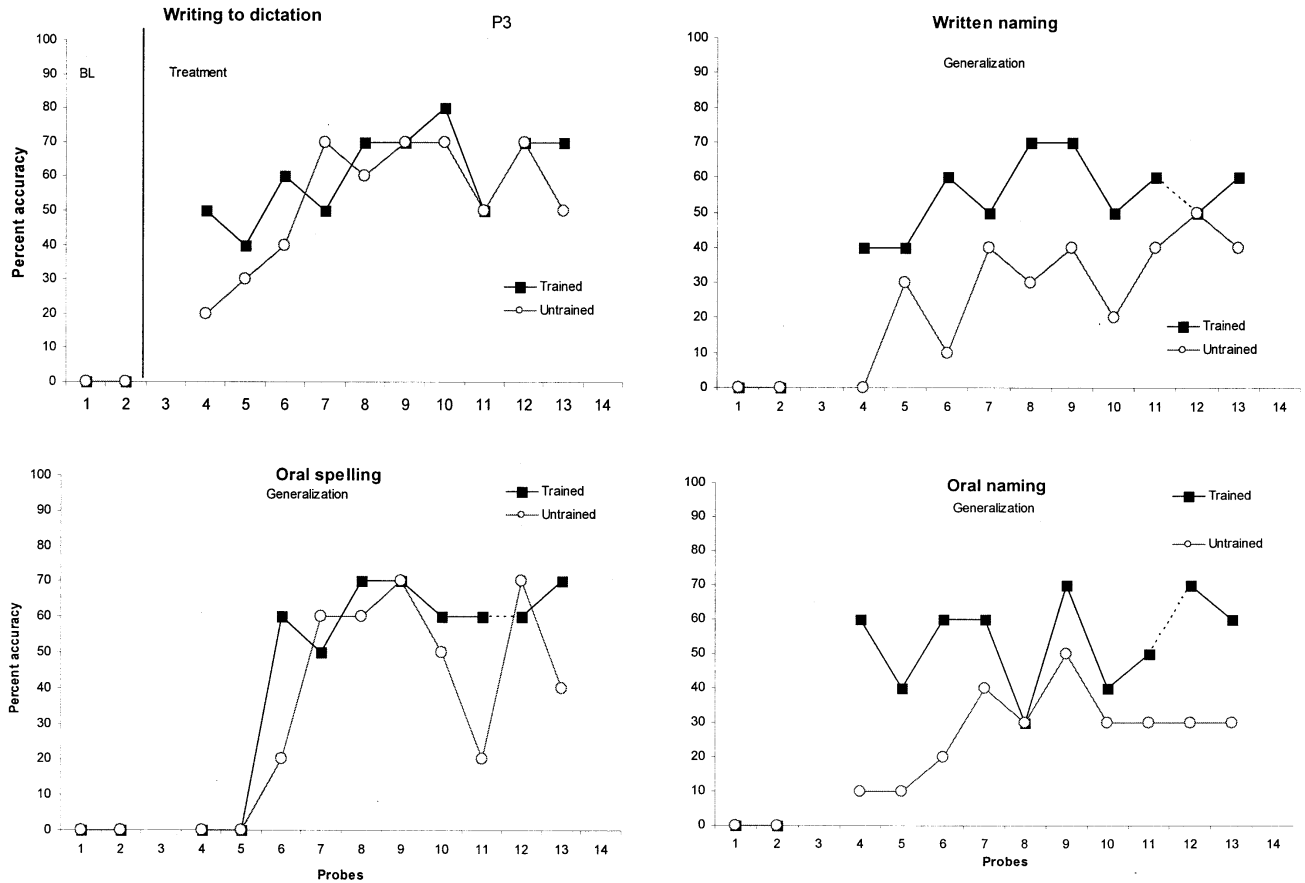

Figure 4. Percent accuracy on trained and untrained items on writing to dictation, written naming, oral spelling, and oral naming for participant 3. Dotted lines indicate a 2-week break in treatment.

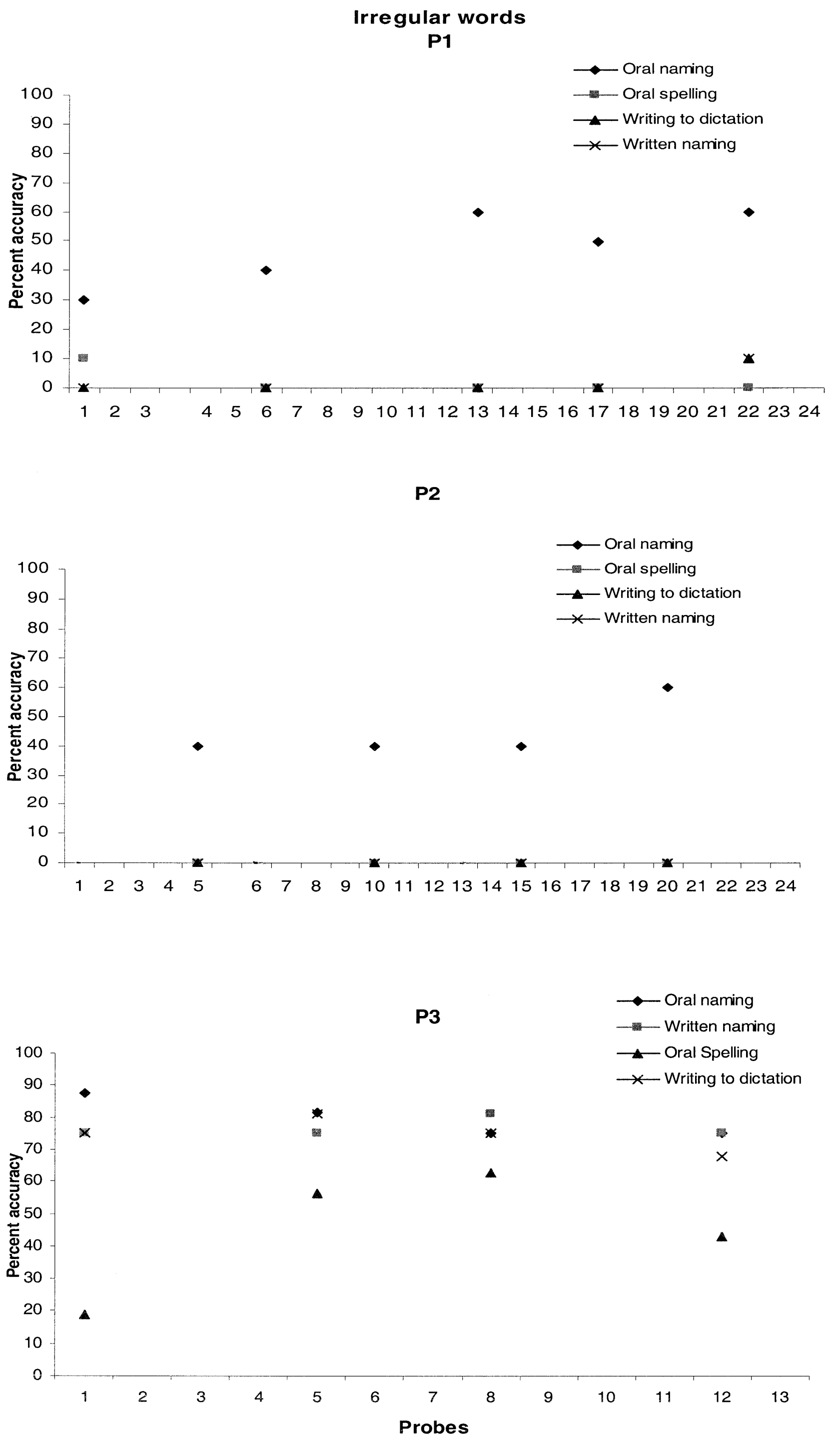

Figure 5. Percent accuracy on untrained irregular words tested during writing to dictation, written naming, oral spelling, and oral naming tasks in participants 1, 2, and 3.

Evolution of errors

For each participant, errors produced during baseline sessions and equal number of sessions at the end of treatment were compared for writing to dictation and written naming tasks. For instance, P1's errors observed during the first three baselines were compared with errors produced during the last three treatment sessions. Statistical analyses comparing the number of errors produced during baselines and end of treatment (with trained and untrained stimuli collapsed) were performed. However, errors produced on trained and untrained are discussed separately in order to better illustrate the differential effect of treatment on these stimuli. The proportions of errors by type across participants are included in Table 2.

Chi-square analyses on writing to dictation showed significant treatment effects for participant 1, χ^2 (7, N = 81) = 69.15, $p < .0001$; participant 2, χ^2 (9, N = 208) = 204, $p < .0001$; and participant 3, χ^2 (7, N = 54) = 27.3, $p < .001$. Prior to initiation of treatment, P1's errors on the writing to dictation task primarily reflected responses that overlapped with target word on less than 50% of letters (83% errors). Following treatment, errors shifted to responses that overlapped with the target on more than 50% of the letters (Trained = 100% errors) and semantic errors (Untrained = 38.8% errors). P2 demonstrated only no responses (38% errors) or indiscernible responses (60% errors) on the writing to dictation task prior to initiation of treatment. Even though this participant did not improve on treatment, errors on the writing to dictation task upon termination of treatment reflected a distinct shift towards errors that contained less than 50% of the target letters (Trained = 70%; Untrained = 79.6% errors). Finally, P3 presented with a predominance of no responses (67.5% errors) prior to treatment, which reduced following treatment (Trained = 50%; Untrained = 37.5% errors); while the number of semantic errors increased for trained words (17.5% to 33% errors) and errors that had overlap with the targets increased for untrained words (see Figure 6).

Patterns of evolution across the three participants on the written naming task illustrated some of the processes underlying generalisation of trained and untrained words on this task. Chi-square analyses showed significant treatment effects for participant 1, χ^2 (9, N = 85) = 62.7, $p < .0001$; participant 2, χ^2 (11, N = 229) = 178, $p < .0001$; and participant 3, χ^2 (8, N = 59) = 27.3, $p < .001$. Participant 1 primarily wrote less than 50% of the target letters correctly (70% errors), however following treatment, he was able to access a majority of the target letters (Trained = 30%; Untrained = 22% errors). Also, P1 did not attempt responses (57% errors) on trained words he could not access and made semantic errors (44.4 % errors) on untrained words. P2 demonstrated a shift from essentially producing no responses (37% errors), indiscernible responses (30.3% errors), or drawing the target picture (23% errors) prior to initiation of treatment to accurately writing less than half of the target letters (Trained = 59.3%; Untrained = 53.1% errors). Finally, P3 mainly produced no responses (57.5% errors) and some semantic errors (28% errors). While the number of no responses reduced following treatment (Trained = 44.4%; Untrained = 18.1% errors) the number of semantic errors on untrained words (45.5% errors) and responses that had more than 50% overlap with targets on trained words (Trained = 33.3% errors) increased at the end of treatment.

Post-treatment language testing

All tests administered prior to initiation of treatment were assessed again upon completion of treatment and are shown in Table 3. Participant 1 demonstrated improvement on *WAB* and *BNT,* demonstrating overall improvements in language processing as a

TABLE 2

Error analysis on writing to dictation and written naming for trained and untrained items for P1, P2, and P3. The total number of responses are followed by percent error type within each catetory.

	P1			*P2*			*P3*		
		End of Treatment			*End of Treatment*			*End of Treatment*	
	Baseline	*Trained*	*Untrained*	*Baseline*	*Trained*	*Untrained*	*Baseline*	*Trained*	*Untrained*
Writing to dictation									
Number of errors	*60*	*3*	*18*	*100*	*54*	*54*	*40*	*6*	*8*
No response	0%	0%	0%	38%	0%	0%	67.50%	50.00%	37.50%
Less than 50% correct	83.30%	0%	22.20%	0%	70.30%	79.60%	7.50%	17%	25.00%
More than 50% correct	11.67%	100%	27.78%	0%	16.67%	9.26%	7.50%	0%	25.00%
Picture	0%	0%	0%	0%	9.26%	7.41%	0%	0%	0%
Indiscernible	0%	0%	0%	60%	0%	0%	0%	0%	0%
Semantic error incorrect	3.30%	0%	11.10%	0%	0%	0%	0%	0%	0%
Semantic error correct	1.60%	0%	38.80%	1%	3.70%	3.70%	17.50%	33.30%	12.50%
One letter correct	0%	0%	0%	0%	0%	0%	0%	0%	0%
Written naming									
Number of errors	*60*	*7*	*18*	*102*	*64*	*64*	*40*	*9*	*11*
No response	10.00%	57%	11.10%	37.20%	1.56%	1.56%	57.50%	44.40%	18.10%
Less than 50% correct	70.00%	0%	16.67%	1%	59.30%	53.10%	10.00%	0%	9.00%
More than 50% correct	11.67%	29%	22.20%	0%	9.30%	9.30%	5.00%	33.00%	18.10%
Picture	0%	0%	0%	23.50%	23.44%	23.44%	0%	0%	0%
Indiscernible	0%	0%	0%	30.39%	0%	0%	0%	0%	0%
Semantic error incorrect	3.33%	14.20%	5.50%	0%	0%	0%	0%	0%	0%
Semantic error correct	5.00%	0%	44.40%	1.96%	6.25%	12.50%	28%	22.20%	45.45%
One letter correct		0%	0%	5.88%	0%	0%	0%	0%	9.09%

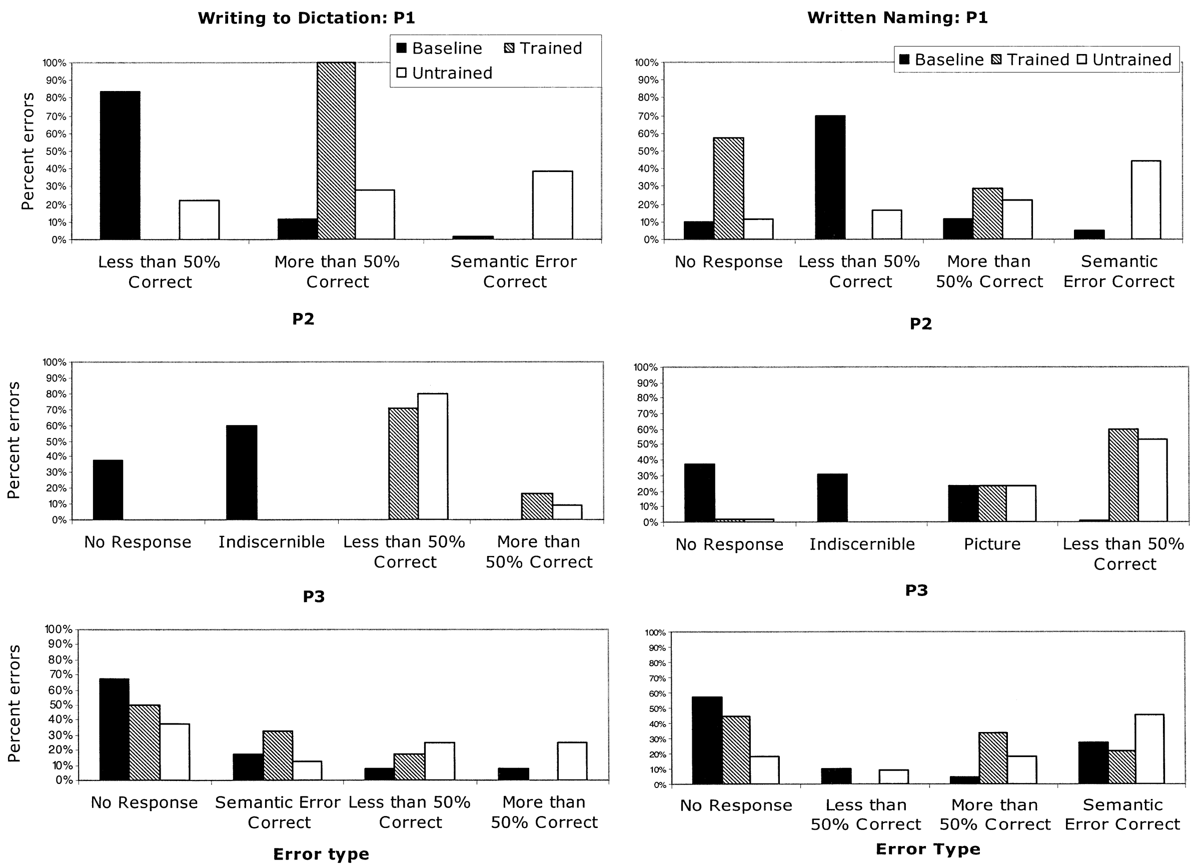

Figure 6. Percent errors produced on baseline and post-treatment (divided into trained and untrained items) during writing to dictation and written naming tasks for participants 1, 2, and 3. For each participant, the number of baseline sessions was equal to the number of post-treatment sessions for which error data were analysed. Only the four most frequent errors for each participant are illustrated here; for a complete distribution of errors see Table 2.

TABLE 3
Pre and post language performance

	P1		*P2*		*P3*	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
Western Aphasia Battery						
Spontaneous speech	13	13	12	9	18	18
Auditory comprehension	10	9.4	6.95	7.45	9.4	8
Repetition	8.6	8.6	5.8	5.4	7.2	7.4
Naming	3.9	7.8	5.7	5.4	7.1	6.9
Aphasia Quotient	73	77.8	60.9	54.5	85.4	80.6
Boston Naming Test (%)	***11.7***	***26.7***	36.7	45.0	66.7	68.3
PALPA						
Same–Different Word Minimal Pairs (%)	94.4	91.7	68.1	DNT	98.6	95.8
Lexical Decision: Imageability (%)	95.0	88.1	78.8	DNT	95.0	96.3
Nonword Repetition Task (%)	73.3	53.3	33.3	DNT	56.7	63.3
Letter Sounding (%)	0.0	0.0	0.0	1.9	76.9	53.8
Letter Naming (%)	***26.9***	***88.5***	0.0	1.9	***44.2***	***55.8***
Spoken letter to written letter matching (%)	***50.0***	***73.1***	***50.0***	***69.0***	88.5	84.6
Letter Length Reading (%)	***70.8***	***83.3***	70.8	79.0	91.7	95.8
Reading Task (%)	***54.2***	***83.3***	***41.7***	***58.0***	58.3	62.5
Spelling–Sound Regularity Reading Task (%)	63.3	61.7	***40.0***	***58.0***	55.0	61.6
Nonword Reading Task (%)	3.3	6.7	0.0	0.0	0.0	4.0
Regularity & Spelling (%)	0.0	5.0	0.0	5.0	***0.0***	***50.0***
Nonword Spelling Test (%)	0.0	0.0	0.0	0.0	0.0	0.0
Spoken Word–Picture Matching (%)	***87.5***	***97.5***	90.0	85.0	95.0	97.5
Written Word–Picture Matching (%)	***87.5***	***97.5***	80.0	85.0	100.0	100.0
Auditory Synonym Judgements (%)	86.7	83.3	76.7	76.0	85.0	78.3
Written Synonym Judgements (%)	81.7	70.0	46.7	56.0	83.3	80.0
Spoken Picture Naming (%)	***35.0***	***52.5***	75.0	77.5	***62.5***	***75.0***
Picture Naming: Writing Picture Names (%)	0.0	5.0	0.0	0.0	***67.5***	***82.5***
Picture Naming: Spelling Picture Names (%)	5.0	7.5	0.0	0.0	80.0	72.5

Pre and post language performance on WAB (Kertesz, 1982); BNT (Goodglass et al., 1983), and PALPA (Kay et al., 1992). Changes exceeding 10% are highighted.

function of treatment. Further, participant 1 also showed improvements on specific subtests of the *PALPA*, including letter naming (26% to 88 % accuracy), spoken letter to written letter matching (50% to 73 % accuracy), oral reading (54% to 83 % accuracy), and picture naming (35% to 52% accuracy); demonstrating some task-specific effects of treatment on reading and spelling skills. Participant 2 did not demonstrate any improvements on either the *WAB* or BNT. Modest improvements were noted on spoken letter to written letter matching (50% to 69% accuracy), and oral reading (40% to 58% accuracy) on subtests of *PALPA*. Participant 3, on the other hand, demonstrated some changes on the *WAB*, specifically on the written subtests (44% to 81% accuracy) although his Aphasia Quotient decreased slightly following treatment (from 85.4 to 80.6). Further, participant 3 also showed changes on letter naming (44% to 55% accuracy), oral spelling (0% to 50% accuracy), written picture naming (67% to 82% accuracy), and oral picture naming (62% to 75% accuracy), demonstrating some task-specific effects of treatment.

DISCUSSION

The present experiment was aimed at extending previous work (Kiran et al., 2001) examining the effectiveness of training sublexical strategies to facilitate single word production. Specifically, in the present experiment, we investigated the effect of strengthening phoneme to grapheme conversion skills in improving writing to dictation skills and consequent generalisation to written naming, oral spelling, and oral naming in three individuals with aphasia. Results revealed that reinforcing phoneme to grapheme conversion (and grapheme to phoneme conversion) rules improved writing to dictation of these words in two out of three individuals with aphasia. Further, access to trained letter names/shapes was also facilitated during written naming and oral spelling consequent to improved written spelling. Additionally, once access to phonemes and graphemes was facilitated for trained words, participants were also able to access corresponding letter shapes during writing to dictation and written naming of untrained words. Marginal generalisation effects to oral spelling of untrained words demonstrated that access to letter names for words that were not directly trained was not as successful as for trained words.

Results from the error analyses of written tasks further explain the effect of treatment. Prior to treatment, all three participants were unable to retrieve any letters of the target words, as evidenced by the predominance of no responses and responses that had less than 50% overlap with the target. Following treatment, all three demonstrated shifts in their errors that reflected a close overlap with the target responses (greater than 50% overlap with targets). Notably, on the written naming task, which assessed generalisation, an increase in the number of semantic errors for untrained words was observed for all participants, suggesting mediation of the semantic system/graphemic output lexicon for untrained words on this task.

These results support our predictions of the beneficial effects of training phoneme to graphemic conversion to improve written production deficits, and are compatible with most models of written word production and spelling (Allport & Funnel, 1981; Beeson & Rapcsak, 2002; Ellis & Young, 1988; Rapp, 2002). Although these models do not necessarily make predictions about patterns of recovery, the present results extend the general premise of these models to include connections that are capable of change as a function of treatment. First, training writing to dictation for a set of regular words strengthened the link between phoneme to grapheme conversion and the grapheme level (PGC→GL), which was applicable for both written and oral spelling of trained items. Evidence from generalisation to untrained words on written spelling, and to trained words on written naming, reinforces the claim that phoneme to grapheme conversion, grapheme level, and graphemic output lexicon connections (PGC→GL→GOL) were strengthened consequent to treatment. Also, improved written naming of trained items and a shift towards a predominance of semantic errors on the untrained words suggests that lexical semantic–graphemic representation links (SS→GOL) may have been influenced by treatment as well. Therefore, it appears that the present treatment, in addition to emphasising sublexical conversion strategies, influenced the lexical-semantic system as well. Evidence converging on this claim includes greater improvements on trained than untrained items across tasks and the lack of improvements in nonword spelling, which should also have benefited from PGC treatment.

Participant 1 did not improve on oral naming of trained words, but met generalisation criterion for oral naming of untrained words (from 30% to 70% accuracy). During the course of treatment, participant 1 developed a strategy of verbally scanning the alphabet to retrieve the target letter (*e.g., CAT, ABC, A, ABCDEFGHIJKLMNOKPRST*). While this strategy proved extremely successful for the spelling tasks, when applied for oral naming task this strategy was ultimately counterproductive for this individual. Hence, oral naming of untrained words (for which he attempted to access the whole word) was superior to oral naming of trained words (where the segmentation strategy impeded lexical retrieval). For participant 2, oral naming of trained and untrained words did not achieve criterion although rising trends were observed. The results of these two participants could likely support the premise of Rapp's (2002) model, where in the phonological lexicon and grapheme lexicon are independent of one another, and thus treatment for written word access should have no apparent effect on spoken word access. Participant 3, however, demonstrated improvements on oral naming of trained words (0–70% accuracy) upon treatment for writing to dictation of these words, thereby lending some evidence for our assumption that written production can facilitate oral production. If participant 1's oral naming of untrained items and participants 2's naming trends are included in the argument, support for a bidirectional link between spoken and written representations is strengthened. Therefore, the present results provide modest evidence for our claim that spoken and written representations are mutually accessible (Ellis & Young, 1996; Rapcsak & Beeson, 2002) and training representations in one modality can likely facilitate access to representations in the other modality.

Finally, the lack of any improvement consequent to treatment in participant 2 is problematic since this patient presented with a profile similar to participant 1 (nonfluent aphasia, phonological dysgraphia, impaired PGC and GPC conversion); and was only 2 years post stroke. This participant, however, was more impaired at auditory comprehension (AQ subscore = 6.95) than the other participants. He also presented with phonological processing deficits on subtests of the PALPA (e.g., real word discrimination, nonword repetition) suggesting that success on written spelling may be related to preserved auditory processing abilities. Further, this participant also demonstrated difficulties on tasks that required phonological encoding and/or speech motor programming (e.g., single word repetition, nonword repetition, nonword reading, and oral spelling). Participant 2 did, however, demonstrate a change in the nature of errors produced prior to treatment (e.g., indiscernible responses or pictures of targets) compared to errors produced following treatment (e.g., responses with some overlap to target), implying that treatment did have some influence on written performance. Performance on oral naming of trained, untrained, and irregular words improved modestly during treatment, raising the possibility that repeated exposures to name the targets may have facilitated access to phonological representations.

Improvements on irregular words that were observed for participant 3 also warrant some discussion. Improvements were observed in oral spelling of irregular words during the course of treatment (from 0% to 60% accuracy), although these effects were not statistically significant. This participant was better at irregular words than at regular words prior to the initiation of treatment. However, as treatment progressed he was able to orally spell the irregular words and also demonstrated improvements in oral spelling on post-treatment testing (0% to 50% accuracy). It is likely that training phoneme to grapheme conversion indirectly reinforced the mechanism of oral spelling, which subsequently allowed this participant to spell the irregular words he was able to name.

To summarise, results from the present experiment demonstrate the effectiveness of training phoneme to grapheme conversion in improving written production deficits in two out of three individuals with aphasia. Furthermore, improvements were also observed on untrained words and untrained tasks such as oral spelling, written naming, and oral naming. These findings, taken together with our previous work (Kiran et al., 2001), suggest that training sublexical conversion mechanisms is an efficient way to improve oral and written production deficits. This is because, in both studies, training the sublexical conversion mechanisms improved the trained behaviour (i.e., grapheme to phoneme conversion→oral reading; phoneme to grapheme conversion→writing to dictation), and also facilitated noteworthy generalisation effects for oral naming, written naming, and oral spelling of trained and untrained words. Results from the two studies suggest that connections between reading, naming, spelling, and written tasks draw upon spoken and written representations that are mutually accessible, and training access to one modality of representation can have beneficial effects on the corresponding representation in a different modality. From a clinical perspective, these results advocate a more efficient method of treating single word access compared to traditional treatment programmes focused on a single output modality. Therefore, rather than training each modality successively, careful application of a treatment protocol like the present experiment might result in simultaneous multimodal improvements and, consequently, superior outcome measures.

Manuscript received 29 April 2004
Manuscript accepted 19 October 2004

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APPENDIX

Treatment protocol

1. From the training set, one word was presented and the participant was asked to write the word to dictation. 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 accurate, he was reinforced for his response and proceeded to the next step.
2. The participant was asked to copy the written word.
3. Following this, the participant was asked to orally read the target and feedback was provided.
4. The examiner then presented the letters of the target word and equal number of distracters in a random sequence, and the participant was asked to select and write the sound (e.g., */ruh/ /ae/ /buh/*) of the target word in the correct sequence. If the participant was unable to 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 sound /r/ Here is the letter R.* The examiner guided the participant through the remaining letters of the target word in a similar fashion.
5. The examiner then presented each of the target sounds in a random order auditorily to the participant who was required to write the presented letter (e.g., */buh/,* participant writes *B*). If the participant was unable to write the letter accurately, the examiner provided the letter and ask the participant to copy it.
6. The examiner rearranged the letters with their distractors and the participant was required to write the word as in steps 4 and 5.
7. The examiner presented the target word for the participant to write to dictation. Feedback was provided regarding accuracy. The examiner proceeded to the next word.