A Comparison of Errorless and Errorful Therapies for Dysgraphia after Stroke

Submitted to Neuropsychological Rehabilitation

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Short title: Errorless & errorful dysgraphia therapy

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Key words: dysgraphia, errorless learning, therapy, rehabilitation.

Abstract

Background: Despite the increasing significance of written communication, there is limited research into spelling therapy for adults with acquired dysgraphia. Existing studies have typically measured spelling accuracy as an outcome although speed may also be important for functional writing. As spelling is relatively slow, effortful and prone to errors in people with dysgraphia, minimising errors within therapy could be a factor in therapy success.

Method: This within-participant case-series study investigated whether errorless and errorful therapies would differ in their effects on spelling speed and accuracy for four participants with acquired dysgraphia. Matched sets of words were treated with errorless or errorful therapy or left untreated. Results were collated one week and five weeks after therapy.

Results: Both therapy approaches were successful in improving spelling accuracy. For three participants, equivalent gains were demonstrated following errorless and errorful therapy. One participant made significantly greater improvements in spelling accuracy following errorless therapy. The effects were maintained five weeks later. There was no significant difference in post-therapy spelling speed between the two therapy conditions.

Discussion: The results of this study suggest that both errorful and errorless therapies can be effective methods with which to treat spelling in adults with acquired dysgraphia.

Introduction

The skills required for effective writing and spelling are extremely sensitive to brain damage and are nearly always disrupted in instances of generalised neurological damage (Kaplan, Gallagher & Glosser, 1998). This reflects the inherent complexity of writing and spelling, requiring the active integration of linguistic, motor, perceptual and spatial processes (Rapp, 2002). Acquired dysgraphia refers to an impairment to the linguistic and cognitive aspects of writing and spelling and typically co-occurs with other symptoms of language impairment, often to several linguistic modalities (e.g., spoken word retrieval, auditory comprehension, reading etc.) in individuals with aphasia (Damasio, 1998). Aphasia is a multi-modal language disorder resulting from acquired brain injury, infection, surgical removal of brain tissue, brain tumour, or most commonly, stroke affecting the left hemisphere (Hallowell & Chapey, 2008).

Research into therapy to improve spelling and writing in participants with acquired dysgraphia has predominantly been in the form of single case studies and small case series designs (see Beeson & Rapcsak, 2002). Treatment in these studies has been guided by cognitive neuropsychological models that provide information on which symptoms or spelling processes to treat and on the kinds of participants who may be likely to respond to particular therapies (Whitworth, Webster & Howard, 2005). Therapy, which usually focuses on improving single word spelling accuracy, has aimed to either strengthen the orthographic representations or to develop a strategy for participants to use to compensate for a given impairment, such as phoneme to grapheme conversion.

The literature shows that acquired spelling impairments can to some extent be treated, and that treatment benefits can be maintained. However, anecdotal evidence strongly suggests that therapy for acquired spelling disorders is a neglected aspect of clinical care, which may in part reflect the limited research evidence base. Given the dominance of oral communication in everyday interactions (Nickels, 2002), the treatment of spoken language is often prioritised over written language. However, some authors have contended that writing may be easier to improve (at least for some participants) and more beneficial for communicating or supporting communication in many cases (Beeson & Rapcsak, 2002). A less controversial but also important observation is that written communication, e.g. via the internet and mobile phones, has become increasingly important in vocational, educational and social spheres. In so far as intervention for acquired communication disorders should be guided by the actual communicative needs of adult brain injury survivors, there is a strong need for further basic and clinical research into writing and spelling disorders. In particular, it may be helpful to evaluate the utility of rehabilitation methods with a strong evidence base in related clinical disorders, such as memory impairment. One approach to spelling therapy research which has, until now, been largely unexplored, is the application of the principles of errorless learning (EL).

Errorless Learning

Aphasia and dysgraphia therapy studies have often adopted an errorful (EF) (or trial and error) paradigm for intervention. This means that graded therapy is provided, for example in the form of orthographic cues following an erroneous first response. This approach will inevitably induce errors in the process of gradually shaping the participant's response closer to the target, through correction and graded support from the therapist. In contrast, there has been an increasing body of evidence that errorless training, in which errors are minimised or eliminated from the task, can be equally or more effective in rehabilitation after brain injury, particularly for treating memory impairments. It is important to note, however, that it is difficult to construct a completely errorless task; therefore the term “errorless” is usually used to describe tasks with relatively few errors (Clare & Jones, 2008). Page, Wilson, Shiel, Carter and Norris (2006) define errorless learning as “a teaching technique whereby people are prevented, as far as possible, from making mistakes” (p. 90).

A review by Clare and Jones (2008) found that, in studies comparing errorless and errorful learning for people with memory impairments following brain injury, errorless learning was more successful for relearning words (Baddeley and Wilson 1994; Wilson, Baddeley, Evans & Shiel, 1994; Squires, Hunkin & Parkin, 1997; Hunkin, Squires, Parkin & Tidy, 1998; Page et al., 2006). However, Evans, Wilson, Schuri, Andrade, Baddeley, Bruna, Canavan, Della Sala, Green, Laaksonen, Lorenzi, & Taussik (2000) had mixed results: EL was successful for relearning names but not for route learning or putting information into an electronic aid. Studies by Clare, Wilson, Breen & Hodges (1999), Clare, Wilson, Carter, Gosses, Breen & Hodges (2000) Clare, Wilson, Carter, Hodges & Adams (2001), Clare, Wilson, Carter, Roth and Hodges (2002) and Clare, Wilson, Carter and Hodges (2003) have found that errorless learning can be useful for retraining face-name associations, personal information and use of memory aids for people with dementia. These positive effects of errorless learning have been attributed to the interference of errors in learning when explicit memory is impaired (Baddeley & Wilson, 1994; Page et al., 2006). Explicit memory is devoted to consciously recollecting past experiences, whereas implicit memory is subconscious (Baddley & Wilson, 1994). It is predicted that if errors are eliminated, then intact implicit memory, which cannot distinguish correct from incorrect responses, can be used (Page et al., 2006). In contrast, if errors are made, they are as likely to be remembered as correct responses by the implicit memory system (Page et al., 2006).

Further support for errorless learning has been provided in the neuroscience literature (McCandliss, Fiez, Protopapas, Conway, & McClelland, 2002; McClelland, Thomas, McCandliss, & Fiez, 1999). According to McClelland et al. (1999) a difficulty in learning through errorful tasks could be explained through the Hebbian learning rule: the principle that if a neuron fires another, there will be a strengthened connection between them. Therefore, a pattern of neural activity elicited by an input will reoccur with subsequent occurrences of the same input, regardless of whether it is useful. Errors would, thus, be reinforced in an errorful task, whereas correct responses would be reinforced in an errorless task. In a study combining data from a computational model and Japanese adults, McClelland et al. (1999) showed through computer simulations of a Hebbian learning model why it might be that Japanese adults have difficulty distinguishing [r] and [l] in English: namely, that Hebbian learning reinforced the perception of sounds they had acquired when younger and prevented them from learning this distinction as an adult. They also taught Japanese adults to discriminate between [r] and [l] in an errorless task, which resulted in successful learning.

Based on the findings of these studies, Fillingham, Sage and Lambon Ralph (2005a, 2005b, 2006) investigated the effects of errorless compared to errorful learning on improving spoken picture naming in adults with aphasia. In three studies they found equal gains following errorless training and errorful training. All participants expressed a preference for errorless over errorful therapy as they found it less frustrating and more rewarding. They also found that cognitive abilities (memory, executive/ problem-solving skills and monitoring skills) predicted therapy success overall, and that participants who did better in the errorful condition had better working and recall memory.

In a recent review of errorless learning studies by Middleton & Schwartz (2012), it was concluded that errorless and errorful approaches have generally resulted in equal gains when applied to picture naming therapies for people with aphasia (Conroy, Sage & Lambon Ralph, 2009a, 2009b; Fillingham, Sage and Lambon Ralph, 2005a, 2005b, 2006; McKissock & Ward, 2007). However, they pointed out that EF performs as well as EL despite more feedback usually being provided in EL tasks, and suggested that EF may have an advantage over EL in that it provides more retrieval practice. Tasks with more retrieval practice (i.e. those with more testing) have been shown to be more successful for improving memory than those with more study time and less testing (Cull, 2000; Karpicke & Roediger, 2008; Thompson, Winger & Bartlin, 1978; Wheeler, Ewers & Buonanno, 2003). EF has also been shown to be more successful than EL after long intervals (Fillingham et al., 2006).

Lexical spelling therapies are often partly errorless and partly errorful. For example, a therapy protocol developed by Beeson (1999) includes both Anagram and Copy Treatment (ACT) and Copy and Recall Treatment (CART). ACT first requires participants to write a word unaided, either to dictation or in response to a picture. If the response is incorrect, the letters are then provided in the wrong order and have to be rearranged before the word is then copied. This creates several opportunities for errors to be made. CART, which is then used as the homework task, requires the participant to copy a word and then to cover it and to write it from memory. As the correct spelling of the word is shown before the participant attempts to spell it, errors are less likely to be produced; therefore, it could be viewed as more errorless than ACT.

There has been one published study which has previously compared errorless and errorful spelling therapy in participants with stroke-induced dysgraphia. Raymer, Strobel, Prokup, Thomason & Reff (2010) carried out a cross-over designed study with four participants. These authors noted that “spelling is inherently error-prone, especially in patients with acquired dysgraphia, who often struggle and self-correct misspellings when they use more preserved reading abilities to recognise a spelling error and reattempt the spelling” (p.3, 2010). For the errorless condition a CART task with systematic vanishing cues was employed. The errorful condition consisted of spelling to dictation with increasing cues. They hypothesised that errorless training would be more beneficial than errorful training for these participants. The study found large effect sizes for trained items across both approaches, but against expectations, there was some advantage of errorful over errorless for three of the four participants. The participants preferred the errorless therapy as they found it less frustrating.

Raymer et al.’s (2010) results showed that errorful training led to more improvement in spelling accuracy than errorless training. However, when writing to communicate for everyday needs, speed may also be an important factor. Speed of language processing seems to be a neglected research area in the aphasia literature and accuracy has often been the only outcome measure. According to Crerar (2004) both speed and accuracy data are essential in evaluating treatment effects and planning treatment for people with aphasia. Crerar (2004) re-analysed a study by Crerar, Ellis and Dean (1996), in which comprehension following therapy was only assessed in terms of accuracy. When response times were added into the equation, it was found that processing speed was still substantially lower than that for control participants after therapy, despite accuracy scores being close to those for controls. Therefore, Crerar (2004) argued that accuracy only tells part of the story and that by including speed, clinicians and researchers can gain more insight into participants' comprehension abilities.

Within the aphasia picture naming therapy literature, Conroy, Sage & Lambon Ralph (2009a, 2009b) found that errorless training took less time than errorful training in naming due to quicker responses and more brief instructions by the therapist. This may also be the case for spelling, which can be a time-consuming and effortful process for people with aphasia. If participants learn to write a word more quickly when copying than during an errorful trial and error spelling approach, then it seems plausible that this word will be written more quickly and effortlessly after therapy. The fact of writing trained words more quickly may well support the functional use of these words in everyday writing tasks. It also highlights the more general benefit and ecological need for skills to be prompt and relatively effortless if they are to be used routinely within habitual behaviours. It is hypothesised that, in this study, errorless and errorful therapy methods of retraining lexical orthography will result in similar improvements to spelling accuracy, but that errorless therapy will lead to speedier spelling of target words than errorful therapy.

Study Aims

This study aimed to answer the following questions:

Research Question 1: Will errorless and errorful training methods differ in their effects on spelling accuracy?

Research Question 2: Will treatment effects be maintained after a period of no training?

Research Question 3: Will errorless training result in speedier production of the correct spelling of target words, compared with errorful training?

Method

A within-participant case series design was used to compare the effects of errorless and errorful learning for acquired dysgraphia in terms of spelling accuracy and speed. Four participants with severe dysgraphia took part in this within-subject case series study. They were recruited from two stroke support groups in South Manchester in the North West region of England. To be included in the study, participants had to have an acquired spelling impairment following a stroke as well as sufficient visual acuity and motor ability for writing. Exclusion criteria included a severe impairment in word retrieval (written or verbal), reading or auditory comprehension, as participants needed to be able to follow verbal instructions and monitor their own writing.

Participants were screened on the Comprehensive Aphasia Test (CAT; Swinburn, Porter & Howard, 2004) writing to dictation subtest. A score of between 10% (3/28) and 90%

(25/28) of letters correct was required for entry into the study. Table 1 shows the scores of the participants who were included as well as their demographic information.

Table 1 about here

Background Assessment

Assessment took place once weekly for 60-90 minutes over 8 weeks in each participant's home. Participants underwent comprehensive assessment of their aphasic symptoms with the Western Aphasia Battery (WAB; Kertesz, 2006), the results of which are presented in Table 2. Additionally, a screen of semantic association skills, the Pyramids and Palm Trees Test (PPT; Howard & Patterson, 1992), was implemented, as well as spelling sub-tests 39, 40, 44 and 45 from the Psycholinguistic Assessments of Language Processing in Aphasia (PALPA; Kay, Lesser, & Coltheart, 1992), the results of which are displayed in Table 3. An error analysis of participants' incorrect responses on the PALPA sub-tests (39, 40 and 44) was conducted. Table 4 shows each participant's percentage of each error or response type.

Tables 2, 3 & 4 about here

Summary of Assessment Results

KR presented with severe non-fluent aphasia. She communicated by producing a few single spoken words, writing single words and short sentences, and drawing. She was therefore very motivated to improve her writing so that she could communicate more effectively. Assessment of KR's writing on the WAB confirmed that she had difficulty writing in full sentences. Her written picture description was generally agrammatic, with mainly verbs being omitted. KR's spelling scores were low on all of the PALPA spelling to dictation subtests. She did not have significantly different scores for high and low imageability words (X^2 = 3.57, *df* = 1, *p* = .06) nor high frequency and low frequency words (X^2 = 0.89, *df* = 1, *p* = .35) on the PALPA 40 (Imageability and Frequency Spelling), nor between regular and exception words (X^2 = 0.00, *df* = 1, *p* = 1.00) on the PALPA 44 (Regularity and Spelling). She failed on each attempt at writing non-words (PALPA 45). KR was often aware of her incorrect responses, but could usually not correct them.

Her semantic errors (e.g. smoke → CHIMNEYS) and her difficulty converting phonemes to graphemes on the PALPA 45, indicated that she had a deep dysgraphia (Bub & Kertesz, 1982; Kumar & Humphreys, 2008). The term deep dysgraphia has been used to describe individuals whose symptoms include the production of semantic errors such as LION for TIGER, impaired non-word spelling, and imageability effects, where low imageability words are more difficult to write than high imageability words (Whitworth et al., 2005). Furthermore, her significantly lower scores on 3 and 4 letter words compared to 5 and 6 letter words on the PALPA 39 (Letter Length Spelling) (X^2 = 4.49, *df* = 1, *p* = .03) and her frequent substitution, omission and movement errors (e.g. school →

SCHOOH; fact → FAT; giraffe → GIFFARE) were characteristic of graphemic buffer disorder (Miceli, Silveri & Caramazza, 1985; Sage & Ellis, 2006; Shallice, Glasspool & Houghton, 1995), a peripheral spelling impairment that has been described as being caused by a deficit in the short-term holding mechanism for the orthographic representations of words while writing is planned and executed. Symptoms include inconsistency, length effects (where more errors occur in longer words) and the following error types: letter additions (carpet → CARPERTS), substitutions (carpet →CARPEN), omissions (carpet→ CARPE) and transpositions (carpet → CARPTE) (Rapp, 2005).

DL presented with severe expressive difficulties due to apraxia of speech and aphasia. He communicated through writing single words and gesturing. Like KR, he was keen to improve his writing so that he could communicate more easily. His written picture description on the WAB demonstrated that DL had a profound difficulty with writing. He only managed to write five words, one of which was spelled incorrectly. He did not have significantly different scores for high frequency and low frequency words (X^2 = 2.54, df = 1, p = .11) on the PALPA 40 (Imageability and Frequency Spelling), nor on regular and exception words (X^2 = 0.42, df = 1, p = .52) on the PALPA 44 (Regularity and Spelling). On the PALPA 39 (Letter Length Spelling), his scores on longer words were not significantly different when compared statistically with his scores on shorter words (X^2 = 3.87, df = 1, p = .05). However, a marked length effect was observed when DL's spelling to dictation was assessed on words longer than six letters during baseline assessment. On the PALPA 40 he scored significantly higher on high imageability words than low imageability words (X^2 = 4.98, df = 1, p = .03). DL sometimes knew when he had made an error, but could rarely correct it.

The imageability effect and the fact that he only wrote one non-word in a phonologically plausible manner on the PALPA 45 (Non-word Spelling) suggested that he had phonological dysgraphia (Jefferies, Sage & Lambon Ralph, 2007; Rapcsak, Beeson, Henry, Leyden, Kim, Rising, Andersen & Cho, 2009; Shallice, 1981), a dysgraphia sub-type that has been used to describe people with impaired non-word spelling, lexicality effects (where a non-word such as PEB is spelt as a phonologically similar stored word such as PUB) (Rapcsak, et al., 2009), imageability effects (Whitworth, Webster & Howard, 2005), and word class effects (where content words such as INN are more likely to be spelt correctly than grammatical function words like IN) (Patterson & Lambon Ralph, 1999). However, his most marked impairment seemed to be at the level of the graphemic buffer, due to length effects, inconsistency in spelling, and the fact that the majority of his errors were additions (aunt → AUNST), omissions (banana → BANAN), substitutions (gravity → GRAVITE), and movement errors (tongue → TONGEU).

WM had fluent speech characterised by occasional word finding difficulties and phonological errors. His motivation for taking part in the study was to be able to do crosswords, write shopping lists and take phone messages. WM's writing was fluent with minimal errors on the WAB written picture description task. However, throughout assessment, his spelling was inconsistent: a word that he spelt correctly on one occasion was often spelt incorrectly on the next. The PALPA spelling to dictation subtests showed that his spelling may have been influenced by length (PALPA 39: Letter Length Spelling) although the difference between short words and long words was not significant (X^2 = 1.92, *df* = 1, *p* = .17). He did not have significantly different scores for high and low imageability words (X^2 = 0.91, *df* = 1, *p* = .34) nor high frequency and low frequency words (X^2 = 2.54, *df* = 1, *p* = .11) on the PALPA 40 (Imageability and Frequency Spelling), nor between regular and exception words (X^2 = 1.60, *df* = 1, *p* = .21) on the PALPA 44 (Regularity and Spelling). When asked whether he was happy with erroneous responses, he often said yes; however, when errors were pointed out to him he could sometimes correct them.

Inconsistency in spelling and predominantly addition (ghost → GHOUST), substitution (hotel → HOTOL), omission (potato → POTA) and movement errors (tongue → TOUNGE) pointed to a graphemic buffer disorder (Miceli et al., 1985; Sage & Ellis, 2006). His low score (4/24) on the PALPA 45 (Non-word Spelling), compared to his higher scores for word spelling on other tests also suggests that WM also had phonological dysgraphia (Rapcsak et al., 2009).

JS was a bilingual Polish man who had lived in the UK since he was 7 years old. English was as his dominant language and he described his Polish as being more impaired than his English following his stroke. He presented with fluent aphasia, characterised by phonemic paraphasias with some stereotyped phrases and empty speech. He was interested in taking part in this study to improve his writing so that he could write letters and phone messages again. In his written picture description JS wrote short phrases consisting of words with correct spellings; however, verbs were omitted. On the PALPA spelling to dictation subtests, he did not have significantly different scores for high and low imageability words (X^2 = 3.59, *df* = 1, *p* = .06) nor high frequency and low frequency words (X^2 = 0.40, *df* = 1, *p* = .53) on the PALPA 40 (Imageability and Frequency

Spelling), nor between regular and exception words (X^2 = 0.00, *df* = 1, *p* = 1.00) on the PALPA 44 (Regularity and Spelling). His scores on the PALPA 39 (Letter Length Spelling) were not significantly different for longer words (5 and 6 letters) compared to shorter words (3 and 4 letters) (X^2 = 0.01, *df* = 1, *p* = .94), which suggested that his spelling was not significantly affected by length. However, he only managed to spell one non-word plausibly to dictation (PALPA 45: Non-word Spelling), which implied that he had a difficulty converting phonemes to graphemes (although, the deficit in speech perception may have been a contributory factor here also). JS rarely detected that there were errors in his incorrect responses when asked.

On the PALPA sub-tests, the majority of his errors were due to the substitution, omission or movement of letters (ghost → GHOSE; spring → SPING; aeroplane → EAROPLANE), which suggested a graphemic buffer disorder. However, on more difficult spelling tests (i.e. those with low imageability and low frequency words) such as the Baxter and Warrington Spelling Test he made occasional semantic errors (e.g. plait → HAIR and cruise → WORLD). Together with his impaired ability to write non-words, these semantic errors indicated a deep dysgraphia (Bub & Kertesz, 1982; Kumar & Humphreys, 2008), albeit a milder form than that of KR.

In summary, all participants showed characteristics of a central linguistic spelling deficit (i.e. phonological or deep dysgraphia) as well as graphemic buffer disorder and all had difficulties with detecting and correcting their own errors.

Target Words for Therapy

In order to generate target words for errorful, errorless and control sets, participants were asked to spell to dictation words from several spelling, reading and picture naming assessments, such as the Object and Action Naming Battery (OANB, Druks & Masterson, 2000), the Boston Naming Test (Kaplan, Goodglass & Weintraub, 2001) and the Baxter & Warrington Spelling Test (1994). For a word to be included in a therapy or control set it had to be failed twice at baseline, so each word was tested on two separate occasions. The assessments used with each participant depended on the severity of their spelling. The lists with higher frequency and imageability words such as the OANB and the Boston Naming Test were used initially. Participants who made fewer errors or were less consistent spellers (i.e. spelt a word correctly on one occasion and incorrectly on another) were then tested on more difficult lists, such as the Baxter and Warrington Spelling Test (1994), so that more treatment items could be generated. Additionally, with support from the first author and family members, each participant chose between 5 and 20 functionally useful, personally relevant items to be included in therapy.

<u>Therapy</u>

For each participant, 120 words that were spelt incorrectly to dictation on two attempts were selected for 3 word lists (40 in each) for errorless (EL), errorful (EF), and control (untreated) conditions. Word lists were matched for phoneme and letter length, frequency, regularity and imageability.

Treatment was administered in 8 90-minute sessions over 4 weeks in participants' homes. Each session was divided into 4 blocks of 10 target items and errorless and errorful conditions were alternated (see Figure 1). So session 1 had the following structure: 10 errorless, 10 errorful, 10 errorless, 10 errorful. The order of therapy type was reversed in the second session of each week to control for any order effects such as tiredness. The EL and EF word lists were each divided and a sub-set of 20 words from each set were targeted in each session. Therefore, in sessions 1, 3, 5 and 7, words 1-20 from the EL and EF sets were treated, and in sessions 2, 4, 6 and 8, words 21-40 from each of the EL and EF sets were treated. There was just one 'run-though' of each sub-set per session.

Figure 1 about here

Errorless Therapy

The errorless therapy, which was designed to minimise errors as far as possible, consisted of a copying task (see Figure 2 below). Participants were asked to copy each target word 3 times. The therapist (first author) presented the written word on a card and produced the word verbally for each attempt. In order to encourage self-monitoring, after each attempt, participants were asked whether they were happy with their written responses. After the first and second attempts, the therapist pointed out any errors that were not immediately recognised by the participant by comparing the participant's response to the word on the card. This allowed the participant to correct these errors on the next attempt. If an error was made on the third attempt, the therapist pointed it out if it had not been noticed by the participant; however, the participant was instructed not to correct it, whether it had been recognised or not. Responses were recorded and errors were counted to ensure that minimal errors were produced. The number of incorrect responses per session for each participant is displayed in Table 5. The highest number of incorrect responses in a session was 4 (by WM); however, the mean number per session was 1.3.

Figure 2 about here

Table 5 about here

Errorful Training

Errorful training consisted of a spelling to dictation task with progressive orthographic cues (see Figure 3 below). The therapist said the target word and asked the participant to write it down on a piece of paper. If the word was written correctly on the first attempt, the participant was instructed to copy the word twice more. On each attempt the therapist said the word. However, if the first attempt was incorrect, then the therapist provided an orthographic cue that constituted around 50% of the help needed to write the word correctly. For example, if the word *elephant* was initially spelt as ELEFET then ‘eleph’ was provided. If only one letter was incorrect, for example, KAT for ‘cat’, then the therapist wrote the word, leaving a blank space for the incorrect letter and a choice of two letters. Whether the second attempt was spelt correctly or incorrectly, the full card was then shown and the participant was asked to copy the word, which the therapist produced verbally once more. After each attempt, participants were asked whether they were happy with their response. They were then told by the therapist whether or not the word was written correctly, but not the location of errors, except after the third attempt. Again, responses were recorded and errors were counted to confirm that this task was errorful. As expected, error rates were much higher than those in errorless therapy, with the number of incorrect responses per session ranging from 10 to 33 (see Table 6). The mean number of incorrect responses per session was 19.8.

Figure 3 about here

Table 6 about here

The errorless and errorful therapies were matched in four important ways. Firstly, the target word was attempted 3 times. Secondly, the phonological form of the word was provided for each attempt. Thirdly, participants were encouraged to self-monitor after each attempt and feedback was then given on whether the response was accurate or not. Lastly, the whole word in written form was provided (at different stages) across both therapies.

Post-therapy Assessments and Scoring

Participants were assessed on spelling accuracy of all 120 items from errorful, errorless and control lists one week post therapy to measure immediate therapy effects, and five weeks post-therapy to establish whether any therapy effects had been maintained. Words from each condition were randomised within the list to control for any order effects.

Two different scoring systems were used. Firstly, words were scored on whole word accuracy. A score of 1 was given for each correctly spelt word and a score of 0 for each incorrectly spelt word (whole word score). Secondly, a more fine-grained analysis of number of correct letters per target word was conducted. The scoring system described in the writing subtests of the Comprehensive Aphasia Test (Swinburn, Porter & Howard, 2004) was used. Letters scored 1 point if they were correct and in the correct position relevant to adjacent letters. A score of 0 was given for letter omissions, substitutions, and transpositions (only one of the transposed letters scored 0). 1 point was subtracted from the total score for any additional letters, regardless of the number of additional letters that were included in the response. Finally, semantic paraphasias scored 0. The number of correct letters per set was then calculated and divided by the total number of letters in the target words for each set to obtain a percentage of correct letters per set (letter level score).

To test for scoring reliability, a sample of the data from one participant was scored by both authors. The second author was blinded to the scores given by the first author. The scores given by the second author were divided by the scores given by the first author and multiplied by 100 to obtain a reliability percentage. This was 99.4%.

During assessment a digital voice recorder was used to record spelling speed. The therapist said the word ‘done’ as soon as the participant had finished writing the word (if correct) or as soon as the participant signalled that he/she had finished writing or wanted to move on (in the case of no responses or incomplete/ incorrect attempts). Goldwave software was then used to measure the response times of correctly spelt items. The response time was defined as the time between the end of the therapist’s production of the target word and the beginning of the word ‘done.’

Results

The results will be set out in order to directly answer the research questions proposed at the end of the introduction. The results have, therefore, been set out as follows:

1. Accuracy immediately post-therapy
2. Accuracy at follow-up assessment
3. Speed of spelling

1. Accuracy Immediately Post-therapy

Research Question 1: Will errorless and errorful training methods differ in their effects on spelling accuracy?

Whole word scores

Whole word accuracy scores for each participant are displayed in Figure 4. Participants have been ordered according to total baseline spelling scores on the PALPA subtests, with the most impaired to the left and the least impaired to the right.

Figure 4 about here

To establish whether therapy was effective, these scores were compared to baseline. For all sets, the baseline score was 0/40, as items included into therapy and control sets had to be failed at baseline on two occasions. The mean scores on both errorless (23.25/40) and errorful sets (20/40) were significantly higher post therapy (EL: $X^2 = 29.64$, $df = 1$, $p < .001$; EF: $X^2 = 23.77$, $df = 1$, $p < .001$). All participants improved significantly following both therapy conditions (McNemar 1-tailed, $p < .003$ for all participants). Furthermore, the mean control score (8/40) was significantly higher than baseline ($X^2 = 10.19$, $df = 1$, $p = .001$), and each participant's control score improved significantly (KR: McNemar 1-tailed, $p = .01$; DL: McNemar 1-tailed, $p = .02$; WM: McNemar 1-tailed, $p = .001$ and JS: McNemar 1-tailed, $p = .002$).

A comparison of mean whole word errorless and errorful therapy scores showed that there was no significant difference between the effects of the two therapies ($X^2 = 0.20$, *df*

= 1, p = .66). This was the case for three of the participants (KR, WM & JS). However, DL performed significantly better on errorless therapy target words (X^2 = 4.17, df = 1, p = .04). The mean control score across the participants was significantly lower than both the mean errorless score (X^2 = 10.19, df = 1, p = .001) and the mean errorful score (X^2 = 6.57, df = 1, p = .01). Individual analyses showed that this pattern was consistent across three of the four participants (KR, DL and JS). One participant, WM, did not perform significantly better on items targeted in either errorless (X^2 = 0.06, df = 1, p = .80) or errorful therapy (X^2 = 0.00, df = 1, p = 1.00) compared to controls.

Letter level scores

Letter level scores (percentage of letters correct per set) are displayed in Table 7. Scores were compared to baseline (a mean of the two baseline scores). The mean letter level score improved significantly for both therapy conditions (Errorless: X^2 = 18.5, df = 1, p < .001; Errorful: X^2 = 21.78, df = 1, p < .001). This reflected the results of DL, KR and JS (Errorless: DL: X^2 = 29.34, df = 1, p < .001; KR: X^2 = 32.77, df = 1, p < .001; JS: X^2 = 38.21, df = 1, p < .001; Errorful: DL: X^2 = 10.93, df = 1, p < .001; KR: X^2 = 58.36, df = 1, p < .001; JS: X^2 = 43.47, df = 1, p < .001). However, WM did not have significantly higher scores for either of the conditions. In contrast to the whole word scores, the mean letter level score for control sets was not higher than baseline. The only participant who had a significantly higher score was JS (X^2 = 13.9, df = 1, p < .001).

A comparison of mean letter level scores across therapy conditions did not show a significant difference between errorless and errorful sets. Only DL had a significantly higher score following errorless therapy (X^2 = 11.59 df = 1, p = .001). The mean errorless and errorful scores were both significantly higher than the mean control score (Errorless:

$X^2 = 12.64$, $df = 1$, $p < .001$; Errorful: $X^2 = 11.01$, $df = 1$, $p = .001$) DL and KR had significantly better scores on errorless (DL: $X^2 = 42.23$, $df = 1$, $p < .001$; KR: $X^2 = 39.21$, $df = 1$, $p < .001$) and errorful sets (DL: $X^2 = 45.6$, $df = 1$, $p = .001$; KR: $X^2 = 48.62$, $df = 1$, $p < .001$) compared to control sets. JS's errorless score was significantly higher than his control score ($X^2 = 7.24$, $df = 1$, $p = .007$); however, his errorful score was not. WM's errorful and errorless scores were not higher than his control scores.

Table 7 about here.

2. Accuracy at Follow-up Assessment

Research Question 2: Will treatment effects be maintained after a period of no training?

Whole word scores

Figure 5 shows the individual whole word follow-up scores for the three conditions. A comparison of immediate and follow-up post-therapy assessment results showed that, despite a trend for numerically lower scores at follow-up, accuracy scores did not change significantly for any of the conditions. There was no significant difference to the mean errorless score (23.25/40 at immediate compared to 20/40 at follow-up) nor errorful score (20/40 at immediate compared to 17.75/40 at follow-up), indicating that therapy effects overall had been maintained (Errorless: $X^2 = 0.25$, $df = 1$, $p = .62$; Errorful: $X^2 = 0.08$, $df = 1$, $p = .78$). Furthermore, the mean control score was not significantly lower at follow-up (Mean: 8/40 at immediate compared to 7.5/40 at follow-up, $X^2 = 0.02$, $df = 1$, $p = .89$). The participants' individual accuracy scores did not change significantly over time for any of the conditions. One surprising change was an increase in JS's control score, which improved from 9/40 at immediate assessment to 14/40 at follow-up. This was not statistically significant, however.

Similar to immediate post-therapy scores, mean whole word follow-up scores for the errorless and errorful conditions were not significantly different to each other (X^2 = 0.08, *df* = 1, *p* = .78). This reflects the results of three participants, KR, WM and JS, whose individual scores were not significantly different across these conditions. However, as was the case for the immediate assessments, DL scored significantly higher on words trained through the errorless therapy (X^2 = 7.15, *df* = 1, *p* = .01).

Figure 5 about here

At follow-up the mean whole word control score was, again, significantly lower than the mean errorless score (X^2 = 7.24, *df* = 1, *p* = .01) and the mean errorful score (X^2 = 4.89, *df* = 1, *p* = .03). The individual results were mixed. DL scored significantly better in the errorless condition than control (X^2 = 14.86, *df* = 1, *p* = .001); however, his errorful results did not differ significantly from control. KR performed significantly better on both errorless (X^2 = 17.31, *df* = 1, *p* = .001) and errorful (X^2 = 26.72, *df* = 1, *p* = .001) therapies compared to control. The results of WM and JS did not differ significantly from control items for either therapy.

<u>Letter level scores</u>

When letter level scores from immediate and follow-up post-therapy assessments were compared, there were also no significant differences for any of the conditions, which provided further confirmation that effects had been maintained.

A comparison of follow-up errorless and errorful scores showed no significant difference between the mean scores. Only DL's scores showed any differences, with his errorless score being significantly higher than his errorful score (X^2 = 10.38, *df* = 1, *p* = .001). The mean errorless and errorful scores were significantly higher than the mean control score (Errorless: X^2 = 11.47, *df* = 1, *p* = .001; Errorful: X^2 = 8.67, *df* = 1, *p* = .003). This was true for DL and KR (Errorless: DL: X^2 = 28.92, *df* = 1, *p* < .001; KR: X^2 = 30.89, *df* = 1, *p* < .001; Errorful: DL: X^2 = 4.56, *df* = 1, *p* = .03; KR: X^2 = 41.42, *df* = 1, *p* < .001). However, JS only scored significantly higher on his errorless set compared to control (JS: X^2 = 5.16, *df* = 1, *p* = .02) and neither of WM's therapy sets had a significantly higher letter level score when compared to his control set.

3. Speed of Spelling

Research Question 3: Will errorless training result in speedier production of the correct spelling of target words, compared with errorful training?

Response times of correctly spelt items (in seconds) were entered into a group analysis comparing the mean speed across errorless and errorful conditions. The reason for only measuring the speed of correctly spelt items was that responses scored as incorrect included no responses and partial responses. If these had been included into the analysis, it would have been unclear whether low mean response times were due to quick writing or failures to retrieve the word. However, by only including correctly spelt words in the analysis, errorless and errorful lists were no longer matched for psycholinguistic variables (e.g. length and frequency). Therefore, an ANCOVA was used to compare the mean response time of each therapy condition while controlling for the variables that have an effect on spelling speed. A Pearson correlation coefficient was computed and a significant positive correlation was found between spelling speed and word length in letters ($r = 0.43$, $n = 173$, $p < .001$) and word length in phonemes ($r = .445$, $n = 173$, $p < .001$) (i.e. longer words had higher response times, so the longer the word, the slower the spelling speed). There was a significant negative correlation between spelling speed and word frequency ($r = -.157$, $n = 173$, $p = .04$) (i.e. words with higher frequency values had lower response times, so the more frequent the word, the faster the spelling speed). These were therefore entered into the ANCOVA as covariates. The ANCOVA showed no effect of therapy type on spelling speed ($F(1, 168) = 0.80$, $p = .37$). Individual mean response times for each therapy are displayed in Table 8.

Table 8 about here

Discussion

A within-subject case series study of four participants with aphasia and spelling difficulties following a stroke was conducted. Two approaches to spelling therapy were compared: one which employed an errorless paradigm, and another which was errorful, i.e. participants learnt word spellings through a trial and error method. The effects of each of these therapies were compared to a control (no therapy) condition in terms of spelling accuracy and speed. It was predicted that errorless and errorful learning would result in similar spelling accuracy, but that errorless learning would lead to speedier spelling of target words.

The results showed that both therapies led to significant improvements in spelling accuracy following therapy, which were largely maintained five weeks later. This pattern was consistent across three participants, KR, DL and JS. WM, on the other hand, performed similarly on therapy and control conditions, suggesting that effects were not due to therapy but rather variability in spelling skill. Furthermore, a more fine-grained letter level analysis of his spelling showed no significant improvements to his spelling following therapy. It was unlikely that any improvements could be attributed to spontaneous recovery because all participants had had their stroke at least one year prior to commencement of the study. Furthermore, KR, DL and JS performed significantly better on treated items than control items suggesting that improvements to spelling were due to therapy.

Spelling accuracy was not significantly different across the two therapy approaches, either for the group as a whole, or for three of the four participants at both immediate and follow-up assessment. However, for one participant, DL, errorless learning was significantly more successful in improving spelling accuracy, both immediately after therapy and at follow-up. In relation to speed of accurate spelling, there was no significant difference between errorless and errorful therapies.

Two participants, KR and JS, performed equally well on relearning spelling following errorless and errorful learning. Therefore, it seems that it was the commonalities of the two approaches that were responsible for their success rather than the differences. Both therapy approaches aimed at strengthening orthographic representations of specific words through repeated exposure to the target word. Furthermore, the tasks in each therapy were matched very closely in order to control for differences that were not associated with ‘errorfulness’ or ‘errorlessness’. In both therapies, participants were presented with the phonological form of the word for each attempt with the aim of strengthening the link between phonology and orthography. The therapies were also similar in that the participant was given three attempts at writing the word and was encouraged to monitor after each attempt. In all cases after the initial sessions, participants started to monitor errors themselves without instruction. This could be a factor that influenced therapy success in these participants and might also partly account for improved control scores. In both therapies feedback was given directly after the response had been written. It seems that therapy success for KR and JS was not dependent on the presence or absence of errors.

A factor that may have had an effect on therapy outcome could be type of dysgraphia. KR and JS were both described as having deep dysgraphia (KR and JS). Both had writing characterised by buffer-type and semantic errors and an inability to write non-words to dictation. There are many examples in the literature in which therapy approaches aimed at strengthening orthographic representations have been successful for remediating spelling in participants with central linguistic impairments (Beeson, 1999; Beeson, et al., 2002; De Partz et al., 1992; Rapp & Kane, 2002; Schmalzl & Nickels, 2006). KR often detected her errors but could not correct them. JS, on the other hand, rarely recognised any errors. It might have been expected that their impaired ability to detect and self-correct errors would give errorless therapy an advantage for these participants. Perhaps because monitoring was encouraged, feedback was given and the correct word was copied, the errors made in errorful therapy did not have a detrimental effect.

Despite all participants having similar spelling characteristics, one participant differed from the others in his response to the two therapies. DL showed higher accuracy scores following errorless therapy than errorful therapy. Like the others, he demonstrated graphemic buffer disorder symptoms; however, in his case these seemed to have a greater effect on his ability to spell a word and might explain his superior scores following errorless therapy. Every attempt at spelling appeared to be a trial-and-error process for DL. For example, in errorful therapy he often signalled that he knew a response was incorrect, and then continued to add letters in the hope that he would reach the correct target, resulting in letter addition errors, which are characteristic of graphemic buffer disorder (Whitworth et al., 2005). His spelling was also extremely inconsistent, i.e. words that he spelt incorrectly on one occasion would often be written correctly on the next. He found longer words more difficult to write than shorter words, and so his sets, which had an average word length of 6.8 letters, included many long words, some of which were 9 or 10 letters in length (e.g. *photograph* and *helicopter*). Longer words are thought to be more susceptible to errors in individuals with graphemic buffer disorder as the additional graphemes put more demands on the impaired buffer's storage capacity (Rapcsak & Beeson, 2002). In longer words there is also a greater chance that parts of the word might be irregular, inconsistent with frequent spelling patterns or impossible to just 'work out', for example, if they contain double letters (an additional difficulty for individuals with graphemic buffer disorder, Rapp, 2002). The fact that errorful learning involves a trial-and-error process might explain why it was a less effective method for DL, who generally had to rely on an unsuccessful trial-and-error approach to spelling.

Previously reported successes of errorless learning have been attributed to the fact that correct responses are reinforced rather than incorrect ones (e.g. McClelland et al., 1999). It seems that in DL's case, repeated exposure to the accurate orthographic form of target words in EL reinforced the correct orthographic representation of these words. Copying tasks, such as copy and recall therapy (Beeson, 1999), have been shown to be successful in other cases of graphemic buffer disorder (Raymer et al., 2003; Rapp & Kane, 2002). As the participant is presented with the written form of the word before an attempt is made to spell, this type of task is typically much more errorless than errorful. Rapp and Kane (2002) discuss possible reasons why strengthening orthographic representations through a repeated study and delayed copy treatment improved the spelling of a participant with graphemic buffer disorder. Firstly they suggest that the buffer's ability to maintain activation of the representations was improved. Their second suggestion is that different processes, such as scanning speed or letter-shape conversion processes within the buffer were strengthened. Thirdly, they postulate that simply strengthening the orthographic representations made them more resilient to graphemic buffer damage. However as this participant showed generalisation to untreated words, it was unlikely that this was the only reason for improvement. Rapp and Kane hypothesised that the effects of this treatment were a result of strengthening of orthographic representations as well as direct or indirect improvement to the buffer.

WM obtained low scores and non-significant differences between therapy and control conditions despite having a relatively high level of linguistic and spelling ability (within the group) prior to therapy. It is difficult to explain these erratic results in terms of his dysgraphia sub-type as his spelling had similar characteristics to the other participants. However, it seems likely that other cognitive abilities might have affected his performance. Throughout the course of the study there was some evidence suggestive of memory impairment, for example, he often forgot therapy sessions. Lambon Ralph, Snell, Fillingham, Conroy & Sage (2010) investigated the relationship between cognitive-linguistic abilities and anomia therapy outcomes in 33 people with aphasia, in order to determine whether therapy effects could be predicted based on background assessments. They found that pre-treatment picture naming ability, phonological ability, but also cognitive abilities (reasoning, problem-solving, attention and visual recall) predicted therapy outcome at immediate and follow-up assessment. Additionally, in their picture naming therapy studies comparing errorless and errorful learning, Fillingham et al. (2005a, 2005b, 2006) found that language abilities did not predict therapy outcome, but that cognitive abilities (recognition memory, executive/ problem-solving skills and monitoring ability) did.

The results of this study have paralleled those of other studies that have compared the effects of errorless and errorful learning for language rehabilitation in people with aphasia and have found no significant differences between the two treatment approaches (Conroy et al. 2009a, 2009b; Fillingham, Sage and Lambon Ralph, 2005a, 2005b, 2006). In contrast, the memory rehabilitation literature has generally shown an advantage for errorless learning (Baddeley and Wilson 1994; Wilson, Baddeley, Evans & Shiel, 1994; Squires, Hunkin & Parkin, 1997; Hunkin, Squires, Parkin & Tidy, 1998; Page, Wilson, Shiel, Carter & Norris, 2006). The disadvantage of errorful learning has been attributed to impaired explicit memory and a reliance on implicit memory, which cannot distinguish between correct and incorrect responses (Baddeley & Wilson, 1994; Page et al., 2006). The similarity in effects of errorless and errorful learning in people with aphasia could therefore be due to intact explicit memory. However, DL, who performed better following errorless learning, did not have any apparent memory difficulties, whereas WM, who performed similarly following both therapies, did. Unfortunately, as cognitive skills were not assessed in this study, the relationship between cognitive abilities and therapy outcomes cannot be explored.

All participants improved significantly on control scores compared to baseline when a whole word scoring system was used. Due to the design of this study, it is difficult to establish the cause of these improvements. The success on these items might have been caused by practice effects, as participants had seen the words twice at baseline. However, there were at least five weeks between baseline and post-therapy assessment, which makes this unlikely. Also, in most cases different control words were spelt successfully at immediate and follow-up assessment. Furthermore, improvement of control items may reflect generalisation of therapy effects, i.e. that participants had acquired phoneme to grapheme conversion rules that benefited them when spelling untreated words. This only seems plausible for the three participants whose therapy effects were higher than control (DL, KR, and JS). Moreover, control items spelt correctly in the post-therapy assessments were a mixture of words with regular and irregular spellings; therefore phoneme to grapheme conversion rules would not have helped them to spell the words accurately. Another explanation could be that the graphemic buffer process was strengthened as a result of therapy. Alternatively, these successful attempts at control items may have reflected improved attention or increased motivation and effort through having therapy, as well as improved self-monitoring.

The results of the current study contrasted with those of Raymer et al. (2010), who also compared the effects of errorless and errorful training on spelling accuracy in four participants with dysgraphia. They found that three out of four of their participants performed significantly better on spelling to dictation in terms of accuracy following errorful learning in contrast to errorful learning, which was maintained at follow-up. The difference in the results between the studies may reflect methodological differences. For example, Raymer et al.'s study incorporated a multiple baseline design with daily probes. They only treated 20 items per condition and they gave intensive homework. Thus, it could be the case that errorful therapy is more successful for improving spelling when it is more intensive. However, the differences could also be attributable to individual differences in participants. The three participants in Raymer et al.'s study for whom errorful therapy was more successful all had different dysgraphia subtypes: phonological dysgraphia (P1), graphemic buffer disorder (P2) and deep dysgraphia (P4), and all had different severities. P3, who had phonological dysgraphia, made more substantial improvements following errorless learning although this was not maintained. Interestingly, P3 and DL (from the current study) shared several similarities in their linguistic and spelling abilities that might have contributed to their better performance on errorless training: they both had severe non-fluent aphasia and a relatively low aphasia quotient (in comparison with other participants) and both used writing as a compensatory communication strategy. Furthermore, both had difficulty spelling non-words and made graphemic buffer type errors (as did all of the participants in this study and all of Raymer et al.'s participants). Raymer et al. concluded from their study that there does not seem to be an association between dysgraphia subtype and success in a certain type of therapy and that more research is needed into other factors that might contribute to spelling performance, such as reading abilities, memory and executive functions.

A possible reason for the better performance following errorful therapy in Raymer et al.'s (2010) study could be retrieval practice (Middleton & Schwartz, 2012). Errorful therapies require the participant to retrieve the phonological or orthographic representation in contrast to errorless therapies in which the word is often repeated or copied. In their errorless condition, Raymer et al.'s participants first copied the word and then gradually had to retrieve parts of the word as they were covered. In their errorful condition, they first had to retrieve the entire word and then parts of it as orthographic cues were provided. The errorful task in the present study also provided more opportunities for retrieval than the errorless task; however, no advantage was found for EF in the short or the long-term, despite otherwise carefully matched tasks.

In a small case series study it has been difficult to draw any conclusions as to whether the suitability of a certain type of therapy can be predicted by the nature of a participant's spelling disorder. Errorless therapy was more successful for DL, a participant with severely impaired, effortful spelling, characteristics of graphemic buffer disorder and poor self-correction skills. However, EL was no more successful than EF for participants with similar spelling characteristics. Future studies could investigate whether the success of errorless learning is related to dysgraphia severity or type, self-detection and correction abilities, or the phase of treatment. It would also be interesting to investigate the relative success of errorless and errorful learning for writing therapies with different treatment goals, for example training phonological skills (e.g. phoneme-grapheme conversion) or self-monitoring skills as this study has focused on methods for retraining lexical orthography. A limitation of this study was that the two therapies were administered concurrently, which, firstly, meant that it was possible that the therapies could have affected one another, and secondly, that it was not possible to compare their generalisation effects. Therefore, there is a need to explore alternative study designs which separate the two therapies being compared and thus reduce any risk of between-therapy interaction.

Errorless therapy does seem to have some advantages over errorful therapy that could be important clinically. Firstly, it was faster to administer. As was found by Conroy et al. (2009a), the difference in the speed appeared to be in the necessity to “manage” errors in the errorful condition. Secondly, it did not require as much input from the therapist. In fact, once participants have been introduced to the method and have been encouraged to self-monitor errors, they would be able to continue to copy words without the presence of the therapist. Therefore, spelling could be practised as homework, which could potentially allow for more words to be targeted. Furthermore, it is likely that, through an increased sense of independence, participants would feel more in control of their rehabilitation, which could lead to increased self-confidence. However, as both therapies were found to be effective, there is an argument for integrating both errorless and errorful approaches but at different phases of therapy. For example, errorless therapy could be used for homework practice or in the early stages of therapy when errors are more likely to occur. Conroy et al.’s (2009a) participants preferred errorless therapy in the initial stages as it enabled them to produce the target words; whereas, as the therapy progressed, those with milder naming impairments found the errorful therapy more challenging and less intrusive.

In conclusion, errorless and errorful learning methods were equally successful in terms of changes to spelling accuracy. Therefore, for aphasic word retrieval, errors do not seem to impede relearning as they appear to in the treatment of memory impairments. Overall, this study has indicated that impairment-based spelling therapy can be successful for improving spelling in adults with a range of spelling impairments, and that these improvements can be maintained for up to five weeks after therapy. Moreover, these positive results were found after a relatively short course of therapy, in which each word was only presented four times in total. This implies that even under time-constraints, spelling is a skill that can be treated effectively for participants with a range of dysgraphic and broader aphasic symptoms. At present, the treatment of oral language is often prioritised for people with aphasia. However, given the increasing importance of writing for communication for participation in professional and social spheres, there is a strong argument for working on writing and spelling, especially for people who cannot communicate verbally.

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Table 1. Demographic Data and Screen Scores

Participants	KR	DL	WM	JS
Age	57	55	74	69
Gender	Female	Male	Male	Male
Education (years)	11	12	10	11
Occupation	Personal assistant	Security guard	Sales assistant/ Factory worker	Lorry driver
Months since stroke	36	27	23	20
Handedness	Right	Right	Right	Right
CAT writing to dictation score (letters correct)	4/28	19/28	18/28	11/28

CAT: Comprehensive Aphasia Test (Swinburn, Porter & Howard, 2004)

Table 2. WAB Scores

Participants		KR	DL	WM	JS	Maximum Score
WAB	Spontaneous speech	0	0	19	17	20
	Comprehension	117.6	182	192	162	200
	Repetition	17	2	78	45	100
	Naming	8	5	87	73	100
	Aphasia quotient	16.2	19.6	90.2	73.8	100
	Reading	50	73	100	76.5	100
	Writing	68.5	53	95	83	100
	Praxis	45	46	60	60	60
	Construction	77.5	88.5	85	80	100
	Cortical quotient	40.85	48.1	92.7	79	100

WAB = Western Aphasia Battery (Kertesz, 2006)

Table 3. PALPA and PPT Scores

Participants		KR	DL	WM	JS	Cut-Off
PALPA 39	3-Letter	6/6	6/6	6/6	6/6	-
	4-Letter	5/6	6/6	5/6	6/6	-
	5-Letter	3/6	5/6	5/6	5/6	-
	6-Letter	2/6	2/6	2/6	5/6	-
PALPA 40	High Imageability, High Frequency	4/10	7/10	8/10	9/10	9.0
	High Imageability, Low Frequency	1/10	5/10	6/10	6/10	8.5
	Low Imageability, High Frequency	0/10	4/10	7/10	4/10	7.7
	Low Imageability, Low Frequency	0/10	0/10	3/10	4/10	6.4
PALPA 44	Regular Words	9/20	14/20	14/20	14/20	-
	Exception Words	8/20	11/20	9/20	15/20	-
PALPA 45	Non-word Spelling	0/24	1/24	4/24	1/24	-
PPT		52/52	52/52	48/52	48/52	49/52

PALPA = Psycholinguistic Assessments of Language Processing in Aphasia (Kay, Lesser, & Coltheart, 1992), PALPA 39 = Letter Length Spelling, PALPA 40 = Imageability and Frequency Spelling, PALPA 44 = Regularity and Spelling, PPT = Pyramids and Palm Trees Test (Howard & Patterson, 1992)

Table 4. Percentage of error types in PALPA 39, 40 & 44

Participant		KR	DL	WM	JS
Semantic		**12.1**	**-**	**-**	**-**
Phonological*	Word	1.5	-	5.3	-
	Non-word	-	-	-	-
	Total	**1.5**	**-**	**5.3**	**-**
Peripheral (buffer-type**)	Addition	-	2.2	7.9	-
	Substitution	4.5	22.2	26.3	37.9
	Omission	1.5	13.3	10.5	3.4
	Movement	1.5	4.4	2.6	3.4
	Mixed	16.7	22.2	26.3	17.2
	Total	**24.3**	**64.4**	**73.7**	**62.1**
<50% of target letters***	Word	6.1	2.2	2.6	10.3
	Non-word	30.3	31.1	18.4	10.3
	Total	**36.4**	**33.3**	**21.1**	**20.7**
Morphological		**19.7**	**-**	**-**	**-**
No response		**6.1**	**2.2**	**-**	**17.2**

*Affected by the sound of the target word: includes phononologically similar words and phonologically plausible non-words. ** See Sage & Ellis (2006); only includes responses with at least 50% letters of target word *** Not phonologically or semantically related to target.

Table 5. Number of incorrect responses per session in EL therapy*

Session	1	2	3	4	5	6	7	8
DL	2	3	0	0	1	1	1	2
KR	1	2	1	1	0	1	0	1
WM	2	3	2	3	2	4	1	3
JS	0	0	1	1	0	1	1	0

*Two or more incorrect responses to the same target word were counted as separate errors.

Table 6. Number of incorrect responses per session in EF therapy*

Session	1	2	3	4	5	6	7	8
DL	33	29	27	22	19	18	19	23
KR	31	33	25	20	23	13	21	10
WM	18	21	19	22	14	14	11	20
JS	19	23	13	19	13	17	10	14

*Two or more incorrect responses to the same target word were counted as separate errors.

Table 7. Letter level analysis scores (%)

		Mean baseline (SD)	Immediately post therapy	5 weeks post therapy
DL	EL	54.2 (2.7)	89.7	82.8
	EF	45.0 (5.3)	69.2	61.3
	Control	40.8 (1.0)	45.6	45.2
KR	EL	50.2 (2.0)	88.6	83.5
	EF	40.5 (6.0)	92.6	88.7
	Control	35.5 (6.6)	46	44.7
WM	EL	45.8 (4.2)	53	55.1
	EF	52.2 (2.3)	63.5	62.1
	Control	42.0 (8.9)	52.1	50.2
JS	EL	29.0 (12.1)	73.8	75.4
	EF	20.7 (0.3)	68.2	73.2
	Control	27.5 (3.2)	54.5	59.3
Mean	EL	45.5 (2.8)	76.3	74.2
	EF	39.6 (3.5)	73.4	71.3
	Control	36.5 (4.5)	49.5	49.9

Table 8. Participants' mean response times (seconds) for accurately spelt words following therapy

Participant	Errorless		Errorful	
	Mean	SD	Mean	SD
KR	11.17	3.25	15.33	12.57
DL	22.64	8.30	27.26	12.77
WM	6.07	0.97	4.74	0.89
JS	7.3	6.63	6.35	4.16
Mean	11.79	7.55	13.42	10.34

Figure 1. Structure of therapy sessions

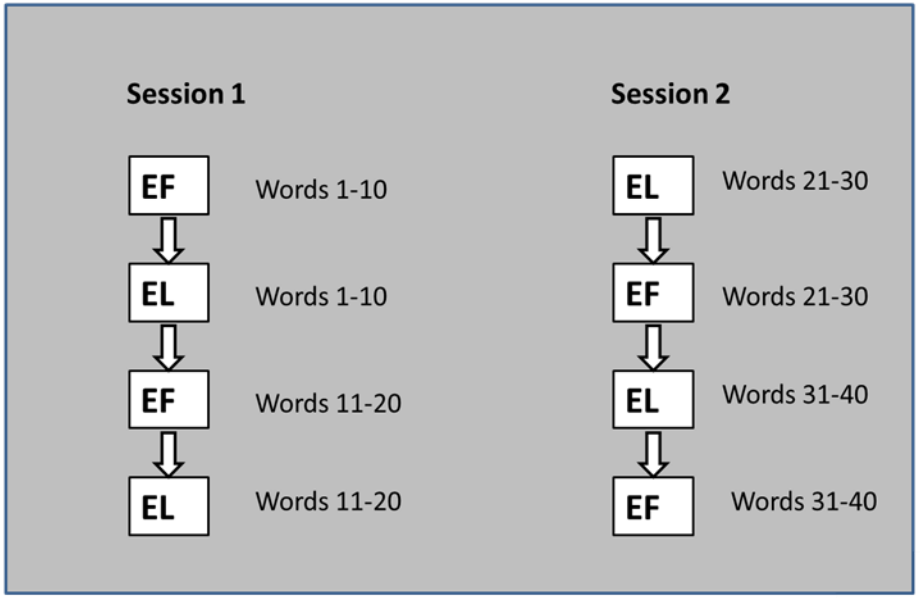

Figure 2. Errorless therapy

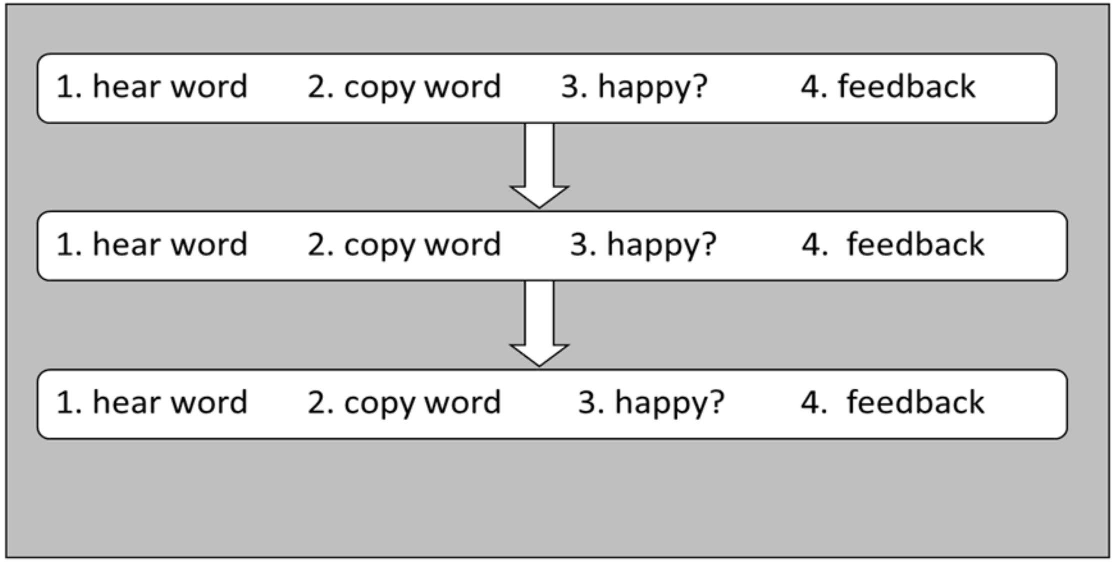

Figure 3. Errorful therapy

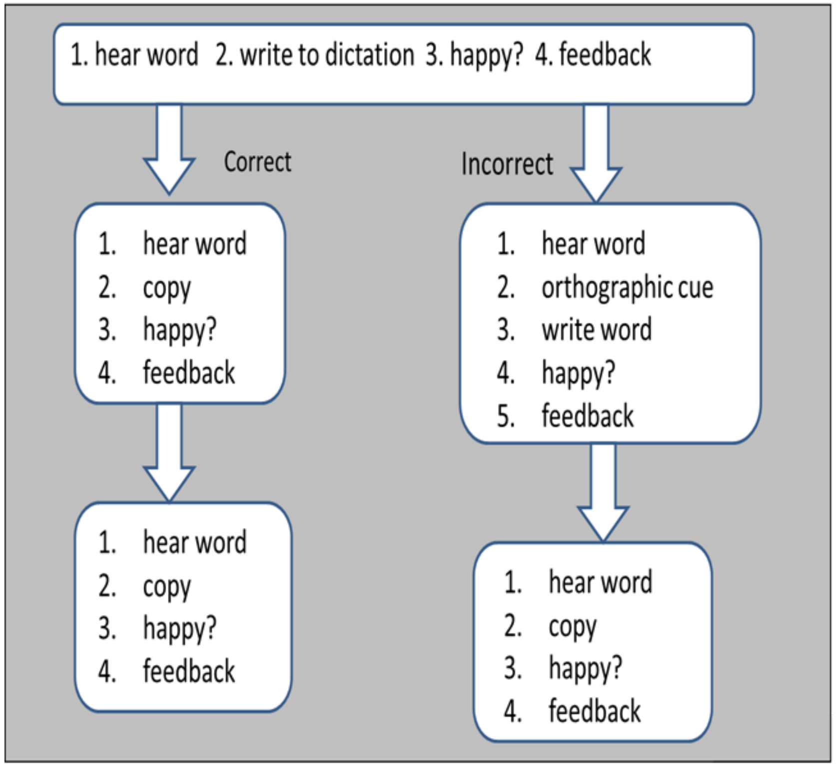

Figure 4. Spelling accuracy scores 1 week post therapy

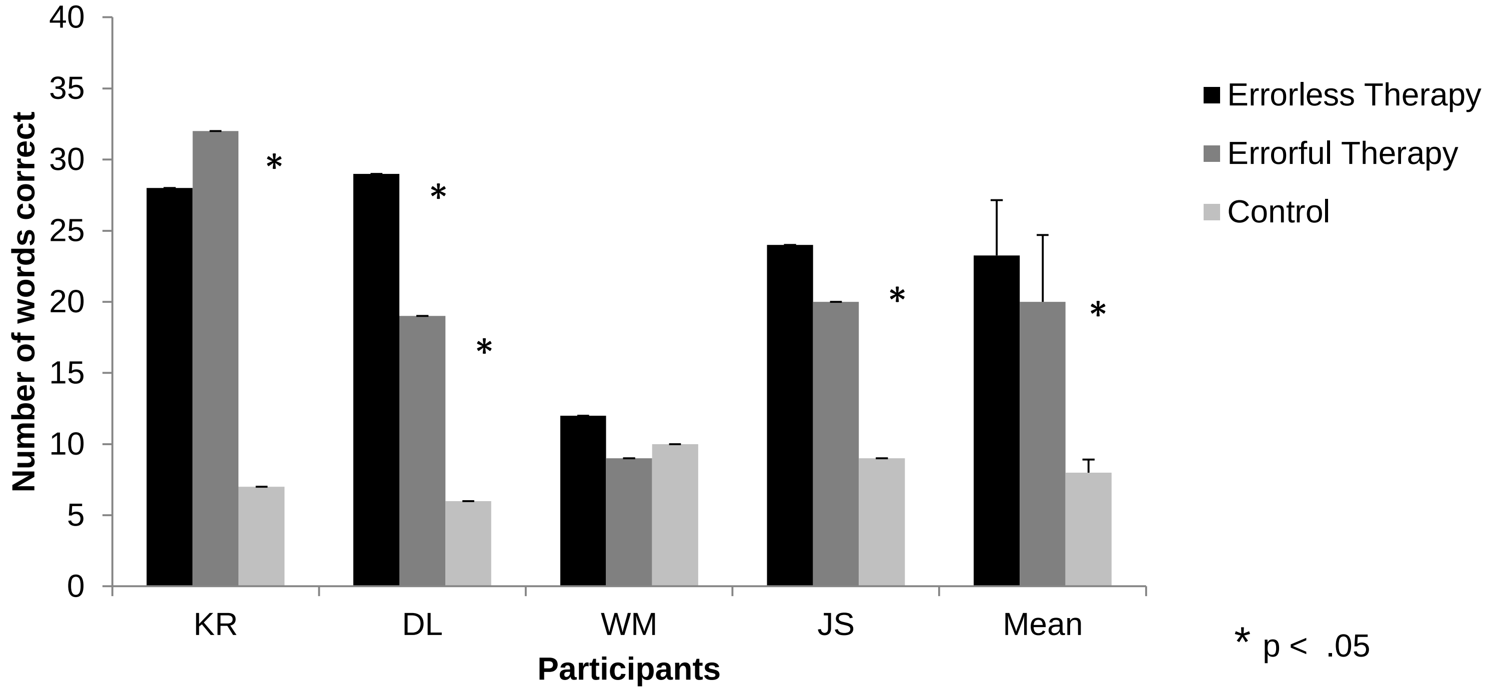

Figure 5. Spelling accuracy scores 5 weeks post therapy