Published in final edited form as:

Aphasiology. 2008 July 1; 22(7-8): 707–717. doi:10.1080/02687030701800826.

A novel method for examining response to spelling treatment

Pélagie M. Beeson,

University of Arizona, Tucson, AZ, USA

Kindle Rising,

University of Arizona, Tucson, AZ, USA

Esther S. Kim, and

University of Arizona, Tucson, AZ, USA

Steven Z. Rapcsak

Southern Arizona VA Health Care System, Tucson, AZ, and University of Arizona, Tucson, AZ, USA

Abstract

Background—According to a dual-route model of written language processing, spelling of irregular words provides an index of the status of lexical spelling procedures, whereas nonword spelling provides information about non-lexical processing that relies on phoneme-grapheme conversion. Because regular words can be spelled using either route, accuracy for such words may reflect the combined function of the two routes, and may be mathematically predicted on the basis of spelling accuracy for irregular words and nonwords.

Aims—The purpose of the present study was to examine the application of a dual-route prediction equation, and a related multiple regression model, to evaluate pre-post treatment spelling performance of individuals with acquired alexia/agraphia.

Methods & Procedures—Eight individuals with language impairment due to left hemisphere damage received behavioral treatment to improve their written spelling. Their spelling performance was examined before and after treatment on untrained word lists with regular and irregular spellings, and pronounceable nonwords, and concurrence between predicted and observed spelling of regular words was evaluated.

Outcomes & Results—The group demonstrated significantly improved spelling performance after treatment, and the prediction equation and multiple regression model both accurately predicted regular word performance on the basis of irregular word and nonword scores. In addition, the multiple regression model provided potentially useful information about the relative contribution of the lexical and non-lexical routes to spelling performance.

Conclusions—The prediction equation and related multiple regression model used in this study can offer novel insight into the cognitive processes available to individuals with agraphia as well as provide a quantitative means to characterize response to treatment.

© 2008 Psychology Press, an imprint of the Taylor & Francis Group, an Informa business

Address correspondence to: Pélagie M. Beeson, P.O. Box 210071, Department of Speech, Language, & Hearing Sciences, The University of Arizona, Tucson, AZ 85721-0071, USA. E-mail: E-mail: pelagie@u.arizona.edu.

Full terms and conditions of use: <http://www.informaworld.com/terms-and-conditions-of-access.pdf>

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Keywords

Aphasia; Alexia; Agraphia; Treatment; Rehabilitation

Literate adults have stored memory for spellings of specific words, as well as knowledge of sound-to-letter correspondences that allow them to generate plausible spellings for unfamiliar words and nonwords. A dual-route model of written language processing posits that these skills reflect distinct but interactive processes referred to as *lexical* and *non-lexical* routes, respectively (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Ellis, 1982; Houghton & Zorzi, 2003; Rapsak & Beeson, 2002; Tainturier & Rapp, 2001). These two routes are depicted in Figure 1 for reading and spelling of single words. Irregular words (such as “choir”) that do not follow conventional sound–letter correspondences are necessarily processed via a lexical route as whole words, whereas nonwords that have no lexical entry (such as “smode”) are decoded by non-lexical (or sublexical) phoneme–grapheme conversion. Regular words (such as “flake”) are unique in that they can be read or spelled using either a lexical or non-lexical route.

Coltheart and colleagues recently suggested that dual-route theory can be used to make quantitative predictions about written language performance (Castles, Bates, & Coltheart, 2006; Coltheart, 2006; Coltheart et al., 2001). Specifically, they proposed that the proportion of irregular words, or $p(\text{IRREG})$, and the proportion of nonwords, or $p(\text{NWD})$, that a person can accurately read provide relatively pure estimates of the competency of the lexical and non-lexical routes. Because dual-route theory posits that either route can process regular words, reading accuracy for these items, or $p(\text{REG})$, should be predictable from $p(\text{IRREG})$ and $p(\text{NWD})$ by the following formula:

$$p(\text{REG}) = p(\text{IRREG}) + [1 - p(\text{IRREG})] \times p(\text{NWD})$$

To illustrate how the equation works, consider an individual who obtains reading scores of 60% correct for irregular words and 30% correct for nonwords, then $p(\text{REG}) = .60 + [1 - .60] \times .30$. The equation predicts that this individual should be able to read 60% of regular words by a lexical strategy, and reading accuracy for the remaining 40% of regular words will be determined by the functional capacity of the non-lexical route, reflected by nonword reading scores (30%). Thus, the dual-route equation predicts a reading score of 72% correct for regular words (i.e., 60% + 12%).

Coltheart and colleagues (Castles et al., 2006; Coltheart et al., 2001) applied this prediction equation to the reading data obtained from young normal readers, children with developmental dyslexia, and children with brain damage due to stroke (total $n = 2246$), and observed high positive correlations between predicted and observed regular word reading scores (ranging from .825 to .980). We recently tested whether such predictions hold for reading and spelling in 33 adults with acquired alexia and agraphia (Rapsak, Henry, Teague, Carnahan, & Beeson, 2007). We found a high correlation between predicted and observed performance for reading ($r = .942$) and spelling ($r = .959$). These findings provide support for dual-route theories of written language processing, and suggest interactive use of residual lexical and non-lexical knowledge by individuals with acquired impairments of reading and spelling (Hillis & Caramazza, 1991; Rapp, Epstein, & Tainturier, 2002).

Behavioural treatments for individuals with acquired alexia/agraphia may be variously directed towards strengthening lexical or non-lexical processing of written language (for a recent review see Beeson & Henry, 2008). Lexical treatments for spelling typically involve retraining specific orthographic representations, and often result in item-specific improvements (e.g., Beeson,

Rising, & Volk, 2003; Rapp & Kane, 2002; Raymer, Cudworth, & Haley, 2003; Robson, Pring, Marshall, Morrison, & Chiat, 1998). In such cases, spelling of trained words improves, but there may be limited generalization to untrained items.

The non-lexical route may be strengthened by phonological treatment that focuses on re-establishing sound–letter correspondences (e.g., Hillis Trupe, 1986; Kiran, 2005; Luzzatti, Colombo, Frustaci, & Vitolo, 2000). Improved function of the non-lexical route may be indexed by better spelling of nonwords, and should boost performance on regularly spelled words. Phonological treatment may also improve irregular word spelling if non-lexical processing helps to cue residual lexical knowledge. In fact, treatment may specifically include training that promotes interactive processing of lexical and non-lexical information (Beeson, Rewega, Vail, & Rapcsak, 2000).

Although improvements in written language processing can be indexed by changes in spelling of regular words, irregular words, and nonwords, these measures do not provide information regarding the extent to which an individual is making optimal use of residual skills. The purpose of this study was to examine the clinical utility of the dual-route prediction equation as a means to evaluate the interactive use of lexical and non-lexical abilities in a clinical context with individuals with acquired impairments of written language. Specifically, we calculated the predicted spelling of regular words on the basis of performance on untrained irregular words and nonwords, and compared the predicted and actual performance on regular words both before and after treatment. Recall that regular words can be spelled using either the lexical or non-lexical routes, and that optimal performance would reflect additive contributions from both sources. Successful treatment is likely to strengthen the component processes for spelling (i.e., improve the function of lexical and/or non-lexical spelling procedures), and we propose that the interaction between the two routes might change over the course of treatment as well. Convergence between predicted and observed performance on spelling of regular words would indicate maximal interactive use of lexical and non-lexical knowledge for a given participant; a mismatch, in which the predicted performance is greater than that observed, would suggest failure to fully integrate available lexical and non-lexical information.

METHOD

Participants

Eight individuals with aphasia due to left hemisphere stroke participated in this study (five male; three female). They ranged in age from 43 to 76 years of age (mean = 59.5) and had an average of 15 years of education (range = 12–19). Time post onset of aphasia ranged from 5 months to 13.5 years (mean = 6.9 years), and neurological status and behavioural performance were stable. Aphasia severity was estimated by the Aphasia Quotient from the *Western Aphasia Battery* (Kertesz, 1982) and ranged from 70.6 to 98.4 (mean = 82.91), indicating participants with minimal, mild, and moderate aphasia severity (see Table 1).

Assessment

Single-word reading and spelling were assessed using controlled lists of stimuli that included regular words (e.g., branch), irregular words (e.g., laugh), and nonwords (e.g., dusp) from the Arizona Battery for Reading and Spelling (ABRS; Henry, Beeson, Stark, & Rapcsak, 2007; Rapcsak & Beeson, 2004). Participants 1–5 were tested with 30 regular and 30 irregular words, and Participants 6, 7, and 8 received a longer version of the ABRS containing 60 regular and 60 irregular words. All participants were tested with a nonword list that included 20 pronounceable one- and two-syllable pseudowords generated by replacing one or two graphemes in real words. The regular, irregular, and nonword lists were matched for word length, and reading and spelling data were collected during different testing sessions.

Pre-treatment assessment indicated that spelling of real words was more impaired than reading for the group as a whole (51.6% correct for spelling versus 81.1% correct for reading), $t(7) = -3.786$, $p = .007$. The group was quite diverse with regard to spelling abilities, as shown in Table 2. Differences in severity and the relative integrity of lexical versus non-lexical processing resulted in a range of spelling profiles that included phonological dysgraphia (in which nonword spelling was more impaired than real word spelling, e.g., Participant 4), surface dysgraphia (in which irregular word spelling was more impaired than regular word and nonword spelling, e.g., Participant 7), and global agraphia (in which very few words or nonwords were spelled correctly, e.g., Participant 1).

Treatment

All participants received behavioural treatment intended to improve written language abilities, with a primary focus on written spelling. They had all demonstrated the ability to relearn item-specific spellings in response to a lexical spelling treatment, and the focus of the treatment for the current investigation was re-training spelling skills that would generalise to untrained words. The treatment approaches were phonological, interactive, or both, as indicated in Table 1 and described below. Treatments were administered either two or three times a week, with daily homework. Treatment duration ranged from 9 weeks to 16 weeks, with an average of 26 hours of treatment administered over 12 weeks (see Table 1).

Phonological treatment was directed towards re-establishing sound–letter and letter–sound correspondences (see descriptions in Beeson & Henry, 2008; Beeson & Rapcsak, 2006). A total of 20 consonants were trained as grapheme–phoneme pairs in groups of 5 until 80% or better accuracy was reached on each set. Following consonant training, two sets of six vowel sounds were trained to the 80% criterion. This training was followed by practice in spelling and blending sounds of nonwords and regularly spelled, low-frequency consonant-vowel-consonant words.

Interactive treatment was designed for use with individuals with relatively preserved sound–letter correspondence abilities, or as a follow-up treatment to enhance the use of newly re-established phonological skills (i.e., following phonological treatment). This treatment involved a problem-solving approach in which participants were trained to use phonological knowledge to generate spellings and to evaluate them on the basis of residual orthographic knowledge. They were also trained to use an electronic speller as an external aid to check and correct spellings (see Beeson & Henry, 2008; Beeson & Rapcsak, 2006; Beeson et al., 2000). In other words, the interactive training consisted of the self-generation of phonologically plausible spellings followed by a lexical decision regarding the correctness of the spelling, and attempts to resolve detected errors. Three individuals received interactive treatment following completion of phonological treatment, and three other participants received it as their primary treatment (see Table 1).

Although spelling was the focus of treatment, changes for both reading and spelling were measured by performance on the regular words, irregular words, and nonwords that were tested prior to treatment; note that these items were not trained during treatment. For each individual, pre-treatment and post-treatment spelling of regular words was examined relative to predicted performance calculated on the basis of the actual spelling of irregular words and nonwords using the dual-route equation described above. Data were examined for the group as a whole in order to test the prediction equation and a related multiple regression model, as well as for individual participants in order to evaluate the potential clinical application of the prediction equation.

RESULTS

As shown in Figure 2, a comparison of pre- and post-treatment performance for the group demonstrated significant improvement in spelling regular words (average gain of 12.25%), $SD = 5.20$; $t(7) = -6.659$, $p < .001$, and irregular words (average gain of 12.13%), $SD = 5.87$; $t(7) = -5.846$, $p = .001$. Nonword spelling improved by an average of 15% ($SD = 18.71$); $t(7) = -2.268$, $p = .058$. For reading, the overall gains were 4.13% for regular words ($SD = 5.22$), $t(7) = -2.234$, $p = .061$, 3.75% for irregular words ($SD = 9.56$); $t(7) = -1.110$, $p = .304$, and 14.1% for nonwords ($SD = 19.13$); $t(7) = -2.088$, $p = .075$. Although real-word spelling improved significantly, reading skills remained stronger than spelling for the group (reading mean = 85%; spelling mean = 63.75%), $t(7) = -3.234$, $p = .014$.

The observed spelling performance for regular words is shown relative to the predicted values derived from the dual-route equation in Figure 3a for pre-treatment data and Figure 3b for post-treatment data. The diagonal 45° line indicates a perfect one-to-one correspondence between predicted and observed performance, so that symbols above the line indicate spelling that exceeded predicted scores, whereas symbols below the line indicate performance below predicted values. The close convergence between predicted and observed values is evident in these scatterplots. Simple regression analyses indicated that the dual-route prediction equation accounted for 92.6% of the variance in actual performance at pre-treatment, $F(1, 6) = 74.960$; $p < .001$ and 86.1% after treatment $F(1, 6) = 37.269$; $p < .001$. Despite the relatively small sample size in this study, the findings are highly consistent with those from our larger cohort of 33 individuals with alexia/agraphia in which the prediction equation accounted for 92.1% of the variance in regular word spelling (Rapcsak et al., 2007).

To further examine the contributions of the lexical and non-lexical processes to spelling in this group of agraphic individuals, we conducted exploratory multiple regression analyses using irregular word and nonword spelling scores as predictors of regular word spelling performance. Both independent variables were entered simultaneously and each variable was evaluated in terms of what it added to the prediction that was different from the other variable in the model. As shown in Table 3, the combination of lexical and non-lexical variables accounted for 92.5% of the variance for regular word spelling before treatment, and 95.5% of the variance after treatment. In addition, individual t -tests showed that irregular and nonword scores each made significant unique contributions to explaining the variance in regular word spelling both before and after treatment (see Table 3). However, the total variance accounted for by the model was partitioned differently after treatment, in that there was a larger proportion of shared variance compared to pre-treatment (53.8% versus 40.4%), and nonword spelling accounted for a smaller portion of the unique variance after treatment.

We also examined the observed and predicted scores for regular word spelling for each participant in order to determine whether the application of the dual-route equation would be informative at an individual level. Chi-square tests of association were calculated to compare the proportions of correct and incorrect responses for predicted versus observed performance for each individual. The actual and predicted scores were congruent for six of eight of the participants (see Table 2). Of particular interest were Participants 3 and 4 who performed below expectation on regular word spelling (by 28% and 20%, respectively) based on their irregular word and nonword spelling performance after treatment. Despite the fact that these individuals showed markedly improved performance in non-lexical processing after treatment (see Table 2), they did not appear to take full advantage of this information when spelling regular words.

DISCUSSION

The purpose of this study was to examine the clinical application of the dual-route equation that was previously shown to predict performance in children learning to read, as well as paediatric and adult dyslexic/dysgraphic populations (Castles et al., 2006; Coltheart et al., 2001; Rapsak et al., 2007). The pre-post treatment performance of a group of eight individuals with impairments of written language provided the context to evaluate the clinical use of the equation. Both before and after treatment, the spelling of regular words was predicted with a high level of accuracy on the basis of lexical knowledge (estimated by irregular word spelling) and knowledge of phoneme-grapheme correspondences (estimated by nonword spelling). This concurrence between predicted and observed performance suggests that individuals were making relatively good use of available information from both the lexical and non-lexical routes when spelling regular words.

It is interesting to note that, despite the fact that real-word spelling performance significantly improved for the group following treatment, the concurrence between predicted and observed spelling of regular words was not as strong after treatment (accounting for 86.1% versus 92.6% of the variance). Examination of individual data suggests that this difference was largely accounted for by the performance of Participants 3 and 4, who appeared to under-utilise their improved non-lexical knowledge when spelling regular words. Participant 3 had received phonological treatment, but not interactive treatment, so these findings indicate the need for subsequent treatment to promote maximal use of his improved non-lexical abilities. Participant 4 had received interactive treatment, but the mismatch between her predicted and observed scores provided justification for additional treatment.

With regard to the group as a whole, the multiple regression analysis offered additional insight regarding the contribution of lexical and non-lexical knowledge to the spelling of regular words. Prior to treatment, there were relatively equivalent unique contributions from lexical and non-lexical spelling routes, and a fair amount of shared variance between these two predictor variables (40.4%). Following treatment, the shared variance increased to 53.8%, and there was a decline in the unique variance accounted for by the non-lexical route. We suggest that the increase in shared variance may reflect enhanced interactive processing of lexical and non-lexical information for the group as a whole, despite the limitations noted for Participants 3 and 4. Consistent with this view, the unique variance accounted for by the non-lexical route decreased suggesting stronger interactive use of non-lexical information to assist in the retrieval of lexical information. We present this interpretation with caution, acknowledging the small size in this study and the exploratory nature of the multiple regression analysis, but note that the findings are consistent with clinical impressions from this cohort of individuals. In fact, such a shift in processing was precisely the focus of interactive treatment received by six of the eight participants in this study.

Finally, we note that other researchers have provided strong evidence of interactive processing of lexical and non-lexical knowledge in single cases (Hillis & Caramazza, 1991; Rapp et al., 2002), but to our knowledge the present study provides the first clinical application of a quantitative measure of interactive use of residual lexical and non-lexical processing. In this study we demonstrated that the calculation and examination of the predicted versus observed spelling of regular words can offer unique insight regarding the status of the cognitive processes available to alexic/agraphic individuals and a means to characterise response to treatment that was not clearly evident otherwise. In sum, these findings suggest that the dual-route equation and related multiple regression model warrant further exploration regarding their value in clarifying the nature of cognitive changes in response to treatment.

Acknowledgments

This work was supported by grants DC007646 and DC008286 from the National Institute on Deafness and Other Communication Disorders. The authors thank Brooke White and Maya Henry for their contributions to this paper.

REFERENCES

- Beeson, PM.; Henry, ML. Comprehension and production of written words. In: Chapey, R., editor. Language intervention strategies in adult aphasia. Vol. 5th ed.. Baltimore, MD: Lippincott, Williams & Wilkins; 2008.
- Beeson, PM.; Rapcsak, SZ. Treatment of alexia and agraphia. In: Noseworthy, JH., editor. Neurological therapeutics: Principles and practice. Vol. 2nd ed.. London: Martin Dunitz; 2006. p. 3045-3060.
- Beeson PM, Rewega M, Vail SM, Rapcsak SZ. Problem-solving approach to agraphia treatment: Interactive use of lexical and sublexical spelling routes. *Aphasiology* 2000;14:551–565.
- Beeson PM, Rising K, Volk J. Writing treatment for severe aphasia. *Journal of Speech, Language, Hearing Research* 2003;46:1038–1060.
- Castles A, Bates TC, Coltheart M. John Marshall and the developmental dyslexias. *Aphasiology* 2006;20:871–892.
- Coltheart M. The genetics of learning to read. *Journal of Research in Reading* 2006;29(1):124–132.
- Coltheart M, Rastle K, Perry C, Langdon R, Ziegler J. DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review* 2001;108:204–256. [PubMed: 11212628]
- Ellis, AW. Spelling and writing (and reading and speaking). In: Ellis, AW., editor. Normality and pathology in cognitive functions. London: Academic Press; 1982. p. 113-146.
- Henry ML, Beeson PM, Stark AJ, Rapcsak SZ. The role of left perisylvian cortical regions in spelling. *Brain and Language* 2007;100:44–52. [PubMed: 16890279]
- Hillis AE, Caramazza A. Mechanisms for accessing lexical representations from output: Evidence from a category-specific semantic deficit. *Brain and Language* 1991;40:106–144. [PubMed: 2009445]
- Hillis Trupe, A. Effectiveness of retraining phoneme to grapheme conversion. In: Brookshire, RH., editor. *Clinical aphasiology*. Austin, TX: Pro-Ed.; 1986. p. 255-265.
- Houghton G, Zorzi M. Normal and impaired spelling in a connectionist dual-route architecture. *Cognitive Neuropsychology* 2003;20:115–162.
- Kertesz, A. *Western Aphasia Battery*. New York: Grune & Stratton; 1982.
- Kiran S. Training phoneme to grapheme conversion for patients with written and oral production deficits: A model-based approach. *Aphasiology* 2005;19:53–76.
- Luzzatti C, Colombo C, Frustaci M, Vitolo F. Rehabilitation of spelling along the sub-word-level routine. *Neuropsychological Rehabilitation* 2000;10:249–278.
- Rapcsak, SZ.; Beeson, PM. Neuroanatomical correlates of spelling and writing. In: Hillis, AE., editor. *Handbook on adult language disorders: Integrating cognitive neuropsychology, neurology, and rehabilitation*. Philadelphia: Psychology Press; 2002. p. 71-99.
- Rapcsak SZ, Beeson PM. The role of left posterior inferior temporal cortex in spelling. *Neurology* 2004;62:2221–2229. [PubMed: 15210886]
- Rapcsak SZ, Henry ML, Teague S, Carnahan SD, Beeson PM. Do dual-route models accurately predict reading and spelling performance in individuals with acquired alexia and agraphia? *Neuropsychologia* 2007;45:2519–2524. [PubMed: 17482218]
- Rapp B, Epstein C, Tainturier M-J. The integration of information across lexical and sublexical processes in spelling. *Cognitive Neuropsychology* 2002;19:1–29.
- Rapp B, Kane A. Remediation of deficits affecting different components of the spelling process. *Aphasiology* 2002;16:439–454.
- Raymer AM, Cudworth C, Haley MA. Spelling treatment for an individual with dysgraphia: Analysis of generalization to untrained words. *Aphasiology* 2003;17:607–624.
- Robson J, Pring T, Marshall J, Morrison S, Chiat S. Written communication in undifferentiated jargon aphasia: A therapy study. *International Journal of Language and Communication Disorders* 1998;33:305–328. [PubMed: 10326042]

Tainturier, M-J.; Rapp, B. The spelling process. In: Rapp, B., editor. The handbook of clinical neuropsychology: What deficits reveal about the human mind. Philadelphia, PA: Psychology Press; 2001.

Figure 1.
A dual-route model of single-word processing.

Figure 2.

Average pre- and post-treatment spelling (2a) and reading (2b) of regular words, irregular words, and nonwords by a group of eight individuals with acquired impairment of language. Vertical bars indicate standard error of the mean. * significant pre-post treatment difference at $p < .05$.

Pre-treatment spelling

Post-treatment spelling

Figure 3.

Scatterplots reflecting the predicted versus observed accuracy for spelling regular words before treatment (3a) and after treatment (3b). Predicted performance on regular words is calculated from actual performance on irregular words and nonwords (see text for details). The 45° line indicates one-to-one correspondence between predicted and observed spelling of regularly spelled words.

TABLE 1

Demographic characteristics of participants

Ss	Sex	Age	Ed (years)	TPO (months)	WAB AQ	Aphasia Type	Treatment	Tx Duration
1	M	47	16	162	78.5	Broca's (evolved to Anomic)	Phonological → Interactive	48 hrs. /16 wks.
2	M	67	18	88	80.2	Anomic	Phonological	24 hrs. /12 wks.
3	M	63	12	96	70.6	Conduction	Phonological	17 hrs. /9 wks.
4	F	76	12	108	76.0	Conduction	Phonological → Interactive	37 hrs. /14 wks.
5	F	43	14	78	96.4	Minimal Aphasia	Phonological → Interactive	24 hrs. /12 wks.
6	M	54	14	10	78.2	Anomic	Interactive	28 hrs. /14 wks.
7	M	60	12	5	98.4	Minimal Aphasia	Interactive	20 hrs. /10 wks.
8	F	66	19	70	85.0	Conduction	Interactive	13 hrs. /10 wks.
Mean		59.5	15	77.1	82.9			26 hrs. /12 wks.

Ed=Education; TPO=time post onset; WAB AQ=Western Aphasia Battery Aphasia Quotient.

TABLE 2

Observed (actual) and predicted performance on spelling of irregular words, nonwords, and regular words (in percent correct) before spelling treatment (PreTx) and after (PostTx). Note that Participants 1–5 were tested using 30 regular words, 30 irregular words, and 20 nonwords, and Participants 6–8 were tested using 60 regular words, 60 irregular words, and 20 nonwords

Ss	Irregular		Nonword		Regular Words		
	Observed		Observed		Observed	Predicted	Observed – Predicted
1	PreTx	7	0	0	0	7	-7
	PostTx	10	5	13	13	15	-2
2	PreTx	27	0	27	27	27	0
	PostTx	40	0	47	47	40	7
3	PreTx	3	45	40	40	47	-7
	PostTx	10	75	50	50	78	-28*
4	PreTx	70	10	50	50	73	-23*
	PostTx	80	50	70	70	90	-20*
5	PreTx	70	65	87	87	89	-2
	PostTx	80	85	93	93	97	-4
6	PreTx	55	75	77	77	89	-12
	PostTx	73	75	88	88	93	-5
7	PreTx	62	95	88	88	98	-10
	PostTx	83	85	98	98	97	1
8	PreTx	72	40	90	90	82	8
	PostTx	87	75	98	98	97	1
mean	PreTx	45.7	41.3	57.4	57.4	64.0	-6.6
	PostTx	57.9	56.3	69.6	69.6	75.9	-6.3

Values in bold indicate significant difference between pre-post treatment performance using McNemar test, $p < .065$;

* Indicates standardized residual > 1.00 on simple regression, and a significant difference between predicted and observed performance using χ^2 test of association, $p < .001$.

TABLE 3
Results of multiple regression analyses using irregular word and non-word spelling scores as predictors of regular word spelling accuracy before and after treatment

<i>Spelling</i>	<i>R</i>	<i>R</i> ²	<i>F</i>	<i>df1</i>	<i>df2</i>	<i>p</i>	<i>Predictors</i>	<i>β</i>	<i>t</i>	<i>p</i>	<i>sr</i> ²	<i>Shared variance</i>
Pre-Tx	.962	.925	30.995	2	5	.002	Irregular Nonword	.585 .549	4.309 4.042	.008 .010	.277 .244	.404
Post-Tx	.977	.955	52.886	2	5	<.001	Irregular Nonword	.645 .453	5.562 3.905	.003 .011	.279 .138	.538

*sr*² = square of the semipartial correlation indicating the proportion of unique variance explained by each independent variable in the model.
shared variance = total variance accounted for minus the sum of the unique variance accounted for by the two predictors = [*R*² - (*sr*² irregular words + *sr*² nonwords)].