Multi-step treatment for acquired alexia and agraphia: Two-dimensional analysis of reading and writing errors

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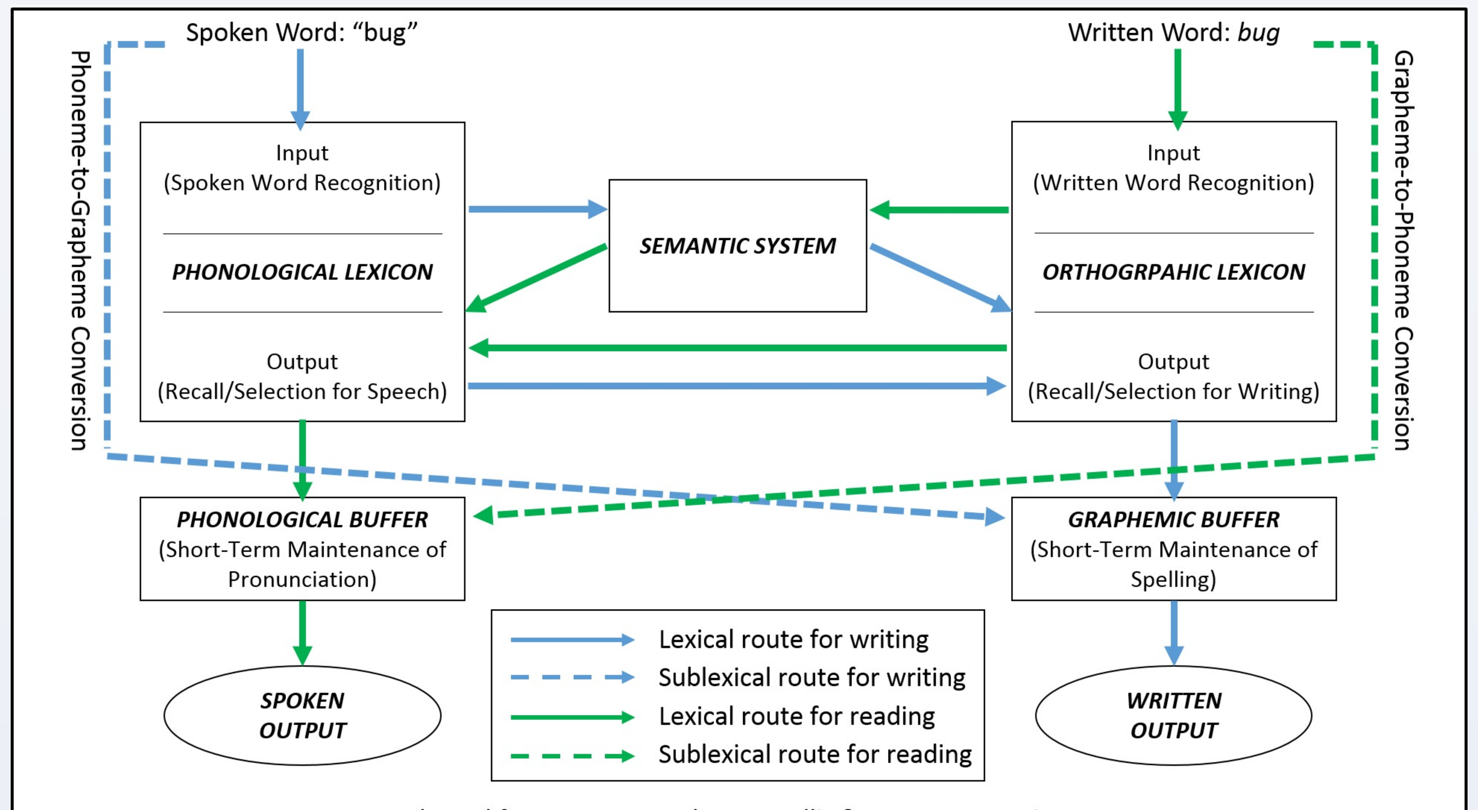
Introduction

- Within a dual-route neuropsychological model, lexical and sublexical routes are distinct but interrelated in reading and writing tasks
- In cases of acquired language disorders, specific locations of breakdown can be identified within both pathways by examining reading and writing errors (Folk & Jones, 2010; Kendall, Conway, Rosenbek, & Gonzalez-Rothi, 2003)
- Individual errors also reveal different severities of breakdown in the two pathways (Kiran, Balachandran, & Lucas, 2014)
- Improvement in one modality (reading or writing) may generalize to the other (Bowes & Martin, 2007; Kiran et al., 2001; Kiran & Viswanathan, 2008)



Adapted from Beeson et al., 2002; Ellis & Young, 2000; Kiran, 2005

- Current error-analysis systems typically focus on:
  - A single pathway (i.e. sublexical, lexical)
  - Binary accuracy (i.e. correct [1]/incorrect [0]), with degree of breakdown as supplemental information only (Beeson et al., 2008; Houghton & Zorzi, 2003; Rapcsak et al., 2007; Rapp & Caramazza, 1997)
- This is the first study we are aware of to assign value to errors (a) in both routes and (b) modalities based on (c) relative accuracy to a target

Objectives

1. Develop a Dual-Route Error Scoring (DRES) system to analyze print processing errors in three ways:
   a. Two-dimensional analysis — hierarchical accuracy in sublexical and lexical routes.
   b. Bimodal analysis — in reading and writing
   c. Objective, quantifiable changes conveying qualitative information
2. Develop an automatized version of the system (ADRES) using Python script to streamline scoring in favor of clinical analysis (Johnson, Ross, & Kiran, 2016)

Participants

- 8 patients with chronic, post-stroke aphasia, alexia, and agraphia

Participant	Treatment Assignment	Age (years)	Time Post-Onset (months)	WAB AQ	Aphasia Type	Alexia Type	Agraphia Type
P1	Writing	51	192	52.6	Broca	Deep	Deep
P2	Writing	58	30	59.7	Wernicke	Deep	Deep
P3	Reading	72	54	37.6	Wernicke	Deep	Deep
P4	Reading	44	20	46.9	Broca	Phon.	Phon.
P5	Writing	66	110	37	Wernicke	Deep	Deep
P6	Writing	70	52	80.6	Anomic	Phon.	Deep
P7	Writing	75	168	90.6	Anomic	Phon.	Deep
P8	Writing	67	72	67.4	Broca	Phon.	Deep
Mean (SD)	–	**62.9 (10.9)**	**87.3 (63.7)**	**59.1 (19.5)**	–	–	–

WAB = Western Aphasia Battery-Revised; AQ = Aphasia Quotient; Phon. = Phonological

Methods

Stimuli

- Trained and related items (n = 48) were probed in both modalities (oral reading, writing to dictation) before, during, and after eight-week treatment protocol (Johnson et al., 2016)
  - 16 trained words
  - 32 related words, matched for frequency and length

Methods (cont.)

Dual-Route Error Scoring (DRES)

- Responses receive a sublexical and lexical score [S#, L#]
- Hierarchies range from 0 (no response) to 9 (successful production of the target)
  - Sublexical scores reflect percent-overlap with the target (> or ≤ 50%), response length (in graphemes/ phonemes), and specific error type (e.g., letter addition, sound substitution)
  - Lexical scores reflect: nature of response (e.g., real word, multi-word, gesture) and semantic accuracy

SUBLEXICAL			LEXICAL	
Target (e.g., "pie") **[S9, L9]**				
Correct length, >50% overlap with target	**GPE** (e.g., "pai" for *pie*)/ **PPE** (e.g., "pea" for *pie*)	**[S8]**	**Target + morphological error** (e.g., "pies")	**[L8]**
	Addition (e.g., "piel")	**[S7]**	**Related word** (e.g., "crust")	**[L7]**
	Transposition (e.g., "pei")	**[S6]**	**Unrelated word** (e.g., "snake")	**[L6]**
	Substitution (e.g., "bie")	**[S5]**	**Related description/circumlocution/gesture** (e.g., "dessert filled with fruit")	**[L5]**
	Deletion (e.g., "-ie")	**[S4]**	**Perseveration – real word** (repetition of a target or response within the previous 3 items)	**[L4]**
	Multiple errors (e.g., "paee")	**[S3]**	**Nonword** (e.g., "piel")	**[L3]**
Correct length ≤50% overlap with target (e.g., "mle")		**[S2]**	**Unrelated description** (e.g., "it's a place you go sometimes")	**[L2]**
Incorrect length ≤50% overlap with target (e.g., "rmle")		**[S1]**	**Perseveration – nonword** (>50% overlap with a target /response in the previous 3 items)	**[L1]**
No response [S0, L0]				

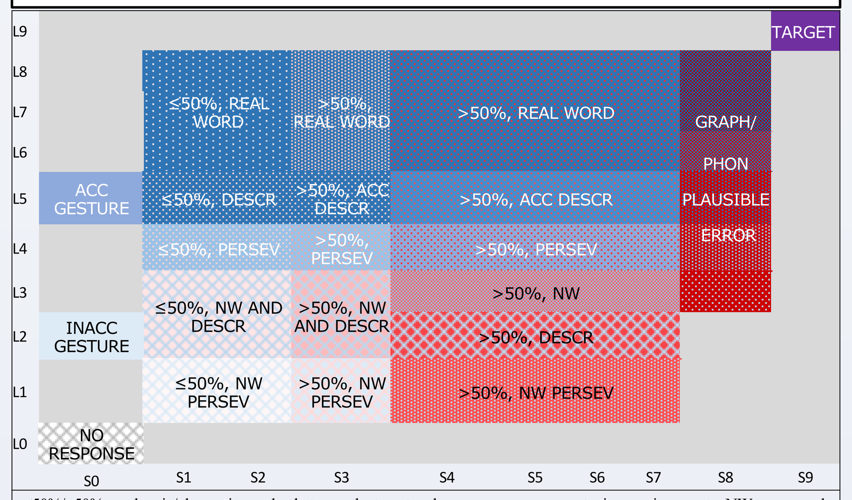
*GPE = graphemically plausible error (written modality); PPE = phonemically plausible error (reading modality); all examples = "response" in quotations for the target word *pie* in italics

Analysis

Objectives 1a, 1b, and 1c

1. Effectiveness of DRES in capturing change (a) two-dimensionally, (b) bimodally, (c) quantitatively and qualitatively
   a. Repeated-measures multivariate analyses of variance (rMANOVA) on averaged scores across time-points
   b. Total scores for every time-point, every patient, and both modalities
      - Sublexical = x-axis, lexical = y-axis
      - Heat maps were used to represent frequency of response types
      - Qualitative analyses of group-level trends in error types
      - Schematic representation: sublexical = red color gradient, lexical = blue

SCHEMATIC GRAPH OF ERROR TYPES



≤50%/>50% graphemic/phonemic overlap between the target and response; acc = accurate; inacc = inaccurate; NW = nonword; descr = description; graph = graphemically; phon = phonemically

Objective 2

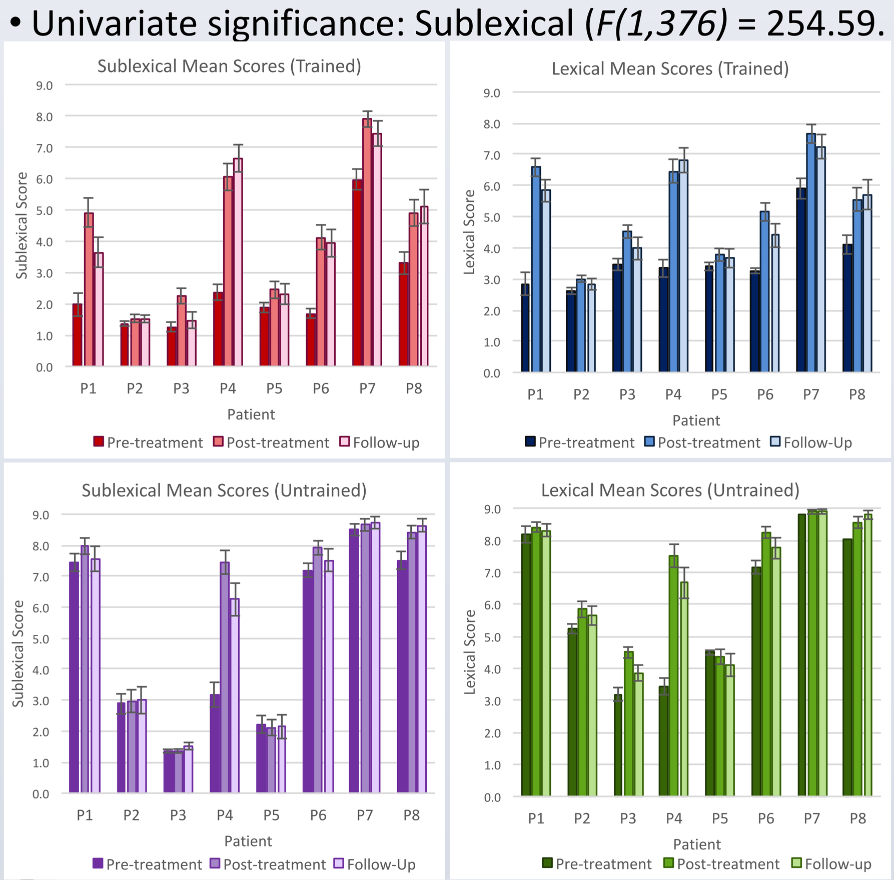
2. Agreement between automated and manual DRES scores for percentage agreement
   - DRES and ADRES scores generated for all responses (n = 5,376) and incongruous scores were analyzed and errors were corrected in both systems

Results

Objective 1. DRES scoring of Treatment Effects

Trained Modality

- Significant treatment effect ($F(2, 375) = 139.97$, $p < .001$, Wilks' $\lambda = 0.57$).
- Univariate significance: Sublexical ($F(1,376) = 254.59$. $p<.001$); Lexical ($F(1,376) = 242.72$, $p<.001$)



- Significant interaction effect of treatment * patient, ($F(14, 750) = 9.80$, $p < .001$, Wilks' $\lambda = 0.72$).
  - Significant domain effect: Sublexical ($F(7,376) = 14.49$; $p<.001$); Lexical ($F(7,376) = 14.88$; $p<.001$)

Untrained Modality

- Significant treatment effect ($F(2, 375) = 59.23$, $p < .001$, Wilks' $\lambda = 0.76$).
  - Significant domain effect: Sublexical ($F(1,130) = 70.32$), $p < .001$); Lexical ($F(1,182) = 118.71$, $p<.001$)
- Significant interaction effect of treatment * patient, ($F(14, 750) = 18.92$, $p<.001$, Wilks' $\lambda = 0.55$)
  - Significant domain effect: Sublexical ($F(1,376) = 28.36$. $p<.001$); Lexical ($F(1,376) = 30.29$, $p<.001$)

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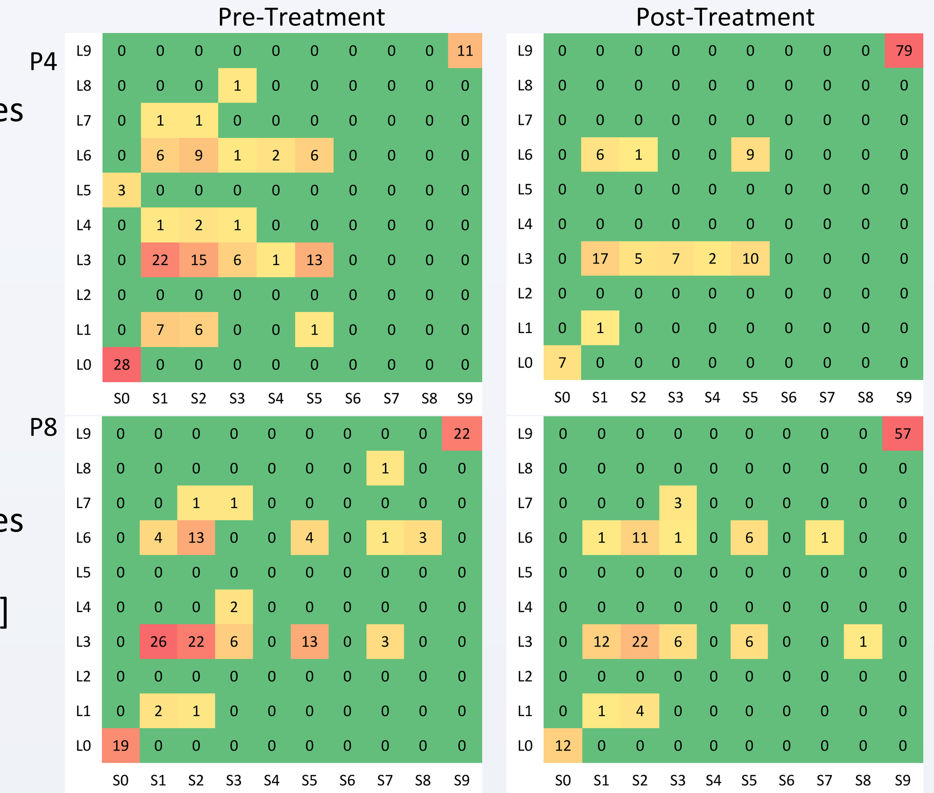
Results (cont.)

Individual DRES Results

- Individual heat maps of 144 items (48 words x 3 probes) pre and post in the trained modality



P4

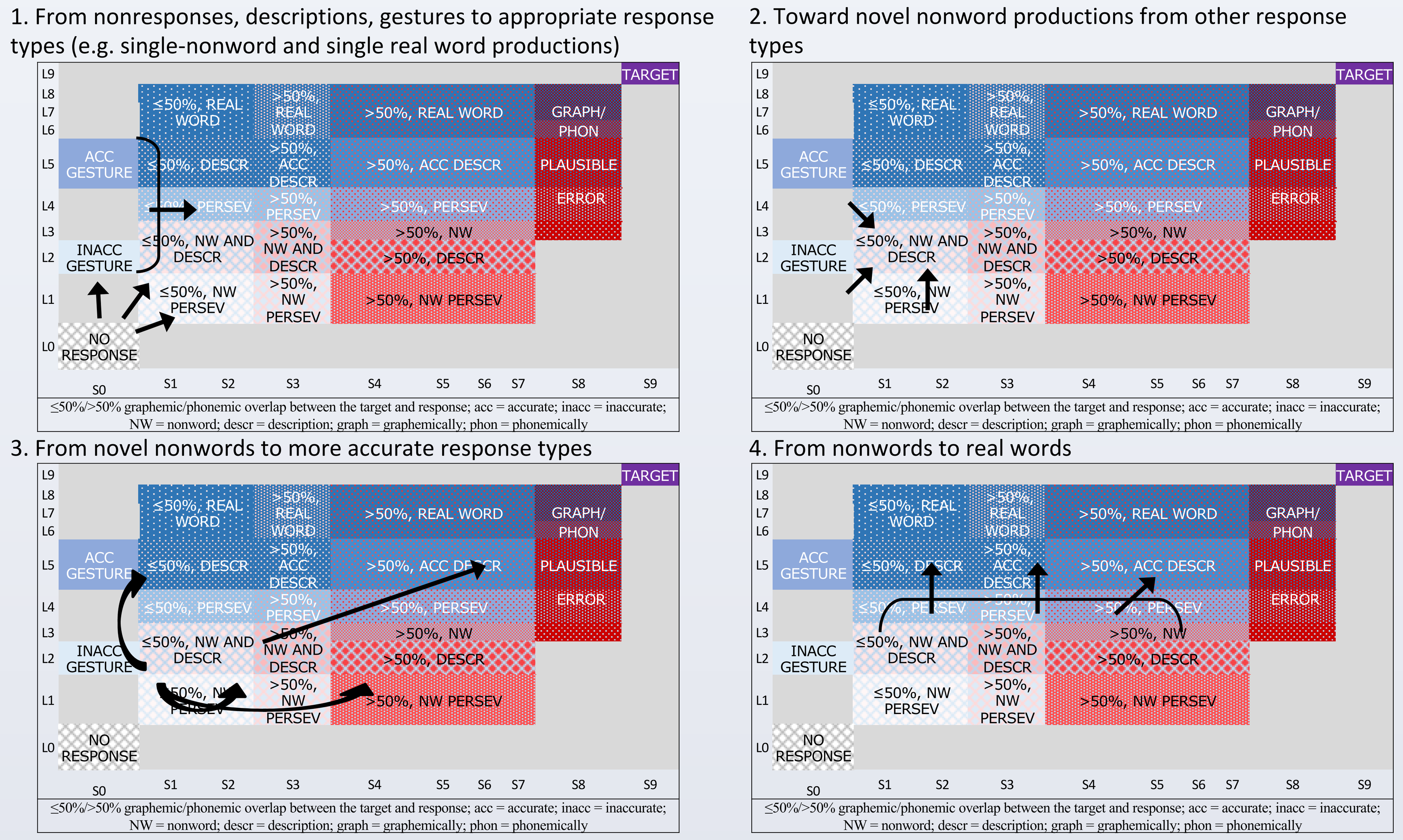
- Trained in reading
- Pre-treatment: very wide spread of scores high volume of non-words ([L3])
- Post-treatment: consolidated lexical scores to mostly single real words ([L6]) and single nonwords ([L3]); whole word improvement ([S9, L9])

P8

- Trained in writing
- Pre-treatment: very wide spread of scores
- Post-treatment: consolidated lexical scores and reduced perseverations (<[L4] and [L1]); whole word improvement

Group DRES Trends

- Four main patterns of error evolution:



Objective 2. ADRES Agreement and Accuracy

- Subexical system agreement = 97%
- Lexical system agreement = 91%
  - Discrepancy is primarily due to related vs. unrelated words
- Ongoing work is being conducted to resolve this and enhance overall ADRES accuracy

Exerpt from Python ADRES script for the sublexical system

```
def main(target, response):
    """ Scores"""
    target = target.lower()
    response = response.lower()
    if "don't know" in response: return 0
    if "not sure" in response: return 0
    if ';' in response:
        '''If multiple responses entered, take the last one afer semicolon as the whole response.
        '''
        response = response.split(';')[-1]
    if len(response) > 1:
        while response[0] == " ": response = response[1:]
        while response[-1] == " ": response = response[:-1]
    if response == target: return 9
    if response == "" or response == "-" or response == "–": return 0
    errors = 0
```

Discussion

- The DRES system captures significant treatment effects as well as significant between-subject differences
  - This is evident in patients' statistical change scores as well as the error evolution shown by individual heat maps
- Multiple patterns of change were observed in individual and group error progressions
- Manual DRES scores were in strong agreement with ADRES scores, indicating reliability and objectivity of the scoring hierarchies
- This scoring system could be used in the future to assess what treatment approaches and elements are most effective for particular clients (e.g. degree of impairment; profiles of aphasia, alexia/ agraphia)
- Research may also be undertaken to evaluate DRES effectiveness in capturing non-print errors, specifically naming as this is most often the focus of treatment for individuals with aphasia