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Effects of semantic context on access to words of low imageability in deep-phonological dysphasia: a treatment case study

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Abstract

Background—Deep dysphasia is a relatively rare subcategory of aphasia, characterised by word repetition impairment and a profound auditory-verbal short-term memory (STM) limitation. Repetition of words is better than nonwords (lexicality effect) and better for high-image than low-image words (imageability effect). Another related language impairment profile is phonological dysphasia, which includes all of the characteristics of deep dysphasia except for the occurrence of semantic errors in single word repetition. The overlap in symptoms of deep and phonological dysphasia has led to the hypothesis that they share the same root cause, impaired maintenance of activated representation of words, but that they differ in severity of that impairment, with deep dysphasia being more severe.

Aims—We report a single-subject multiple baseline, multiple probe treatment study of a person who presented with a pattern of repetition that was consistent with the continuum of deep-phonological dysphasia: imageability and lexicality effects in repetition of single and multiple words and semantic errors in repetition of multiple-word utterances. The aim of this treatment study was to improve access to and repetition of low-imageability words by embedding them in modifier-noun phrases that enhanced their imageability.

Methods & Procedures—The treatment involved repetition of abstract noun pairs. We created modifier-abstract noun phrases that increased the semantic and syntactic cohesiveness of the words in the pair. For example, the phrases “long distance” and “social exclusion” were developed to improve repetition of the abstract pair “distance-exclusion”. The goal of this manipulation was to increase the probability of accessing lexical and semantic representations of abstract words in repetition by enriching their semantic -syntactic context. We predicted that this increase in accessibility would be maintained when the words were repeated as pairs, but without the contextual phrase.

Outcomes & Results—Treatment outcomes indicated that increasing the semantic and syntactic cohesiveness of low-imageability and low-frequency words later improved this participant’s ability to repeat those words when presented in isolation.

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Conclusions—This treatment approach to improving access to abstract word pairs for repetition was successful for our participant with phonological dysphasia. The approach exemplifies the potential value in manipulating linguistic characteristics of stimuli in ways that improve access between phonological and lexical-semantic levels of representation. Additionally, this study demonstrates how principles of a cognitive model of word processing can be used to guide treatment of word processing impairments in aphasia.

Keywords

Deep dysphasia; auditory-verbal short-term memory; language processing; treatment; aphasia; repetition

Introduction

Deep dysphasia is a relatively rare subcategory of aphasia, characterised by specific word repetition impairment and profound auditory-verbal short-term memory (STM) limitation. Michel and Andreewsky (1983) first proposed this diagnostic label to identify individuals who demonstrated error patterns in repetition analogous to the error patterns in reading associated with deep dyslexia (Goldblum, 1981; Morton, 1980). The hallmark features of repetition in deep dysphasia and reading in deep dyslexia are greater accuracy on words than non-words (lexicality effect), greater accuracy for high-image than low-image words (imageability effects) and the occurrence of semantic errors in single-word reading or repetition (Howard & Franklin, 1988). Additionally, auditory-verbal STM capacity is severely reduced. This has been attributed to a rapid decay of the phonological representation (Katz & Goodglass, 1990) or both the phonological and semantic representations (Martin, Saffran, & Dell, 1996) of the word to be repeated.

There is another pattern of impairment in aphasia that is identical to deep dysphasia but for one feature, semantic errors in single-word repetition. The term phonological dysphasia has been used to describe this pattern (e.g., Wilshire & Fisher, 2004). Furthermore, studies indicate that in this group, although semantic errors do not occur in single-word repetition, they are present in multiple-word and sentence repetition tasks (Martin et al., 1996; Saffran & Marin, 1977; Trojano, Stanzione, & Grossi, 1992). This evidence has prompted the hypothesis that phonological and deep dysphasia are the same disorder but are at different points on a severity continuum, which Martin et al. (1996) proposed to be based on the ability to maintain activation of semantic and phonological representations of words in repetition. This ability is hypothesised to support both word processing and auditory-verbal STM span. The evidence that these two syndromes (deep and phonological dysphasia) lie on a severity continuum comes from a longitudinal study of changing error patterns in repetition and verbal STM associated with recovery from deep dysphasia (Martin et al., 1996), reports of semantic errors in repetition of word strings (Martin et al., 1996; Reilly et al., 2012; Trojano et al., 1992) and sentences (Saffran & Marin, 1975), as well as observations of associations between verbal span size and severity of naming and word recognition impairment (Martin & Gupta, 2004).

Proposed accounts of deep dysphasia

The seminal case of deep dysphasia was reported by Michel and Andreewsky (1983) using the influential logogen model of word processing (Morton & Patterson, 1980) to account for the deficit pattern in this syndrome. In this model, input can be auditory via the spoken word or visual via the written word; interaction between levels in the model is assumed. Within this model, Michel and Andreewsky postulated that deep dysphasia resulted from disruption of the sublexical input–output phoneme route and disruption in the connection from input auditory to output logogens. Howard and Franklin (1988) also invoked the logogen model to account for the deep dysphasia pattern observed in a single case study, MK. As in the Michel and Andreewsky (1983) account, Howard and Franklin (1988) postulated two loci of impairment to account for MK's repetition pattern (imageability effects, semantic errors and inability to repeat non-words): the sublexical route and the direct lexical route between the auditory input lexicon and the phonological output lexicon. These two impairments leave only a semantic route to support repetition of words. By this account, semantic representations of words activated by input phonological and lexical activation support activation of output word forms in the output lexicon.

Others have proposed involvement of auditory-verbal STM in deep dysphasia. For example, Katz and Goodglass (1990) reported a case study of SM, who presented with a deep dysphasia pattern of word repetition. They proposed that impairment of phonemic memory affected word repetition and that this impairment affected three possible routes of word repetition, non-semantic (word form repetition), non-lexical (word and non-word repetition) and lexical-semantic (repeating via access to word meanings which activate word forms in the output lexicon).

These early accounts of deep dysphasia agreed that multiple loci of impairment were necessary to account for the poor repetition of words and non-words, and semantic errors in repetition. Katz and Goodglass's addition of a processing account (phonemic memory impairment) illustrates the beginning of a shift away from representational accounts of aphasia. The theoretical framework for the present study is an interactive activation (IA) model of word processing (Dell & O'Seaghdha, 1992) that views aphasia as a processing impairment that affects access to and/or maintenance of activated semantic, lexical and phonological representations of words over the course of comprehending, repeating and producing words. This model and its specific account of deep dysphasia are described later.

Interactive activation account of deep-phonological dysphasia

Dell and O'Seaghdha's (1992) two-step IA model of word production (Figure 1) and its extension to word repetition (Martin, Dell, Saffran, & Schwartz, 1994; Figure 2) provide a theoretical framework for the treatment protocol used in this study. This model, hereafter referred to as the IA model, functions in an interactive, bidirectional fashion. Activation of semantic and phonological representations of words is governed by two parameters: connection weight (strength of activation spread) and decay rate (stability of activation strength). Activation at one level spreads to the next in the form of feedforward spreading activation and also spreads back to the preceding level as feedback. The interactive nature of spreading activation takes place over the time course of word retrieval (Figure 2) and insures

that later stages of word processing (whether phonological in naming or semantic in repetition) influence earlier stages of word processing (semantic activation in naming and phonological activation in repetition). The activation of semantic and phonological representations of a word contributes to the strength of the word (lexical) nodes through the feedforward-feedback process and eventually determines which word node is highest in activation when the intended word is retrieved. Sometimes, the word that is retrieved is the intended (“target”) word (e.g., “cat”) and sometimes it is another word node in the lexicon, often semantically (e.g., “dog”), phonologically (e.g., “mat”) or both semantically and phonologically (e.g., “rat”) related to the target. Impairment to one or both of the processing parameters, connection weight and decay rate, can alter the balance of semantic and phonological input to the activation of the target word and its competitors and lead to the wrong word being selected.

Schwartz, Saffran, Bloch, and Dell (1994) modelled the naming error pattern observed in a case study of FL who demonstrated fluent speech and a high rate of non-words in his production. The model was extended to repetition in the case study of NC, who demonstrated deep dysphasia (Martin et al., 1994; Martin & Saffran, 1992). Martin and Saffran (1992) proposed that a lesion that increased the decay rate of activated nodes in the lexical network could account for the unique symptom of deep dysphasia, namely semantic errors in repetition of single words. Martin et al. (1994) modelled NC’s error patterns in naming and repetition in a computer simulation of word retrieval (Dell & O’Seaghdha, 1992) by increasing the decay rate of activated nodes, but maintaining the normal levels of connection strength. A notable achievement of this modelling study was that a single lesion to the decay rate parameter was able to simulate the high rate of semantic errors in repetition.

In another study, the model was used to address co-occurring changes in error patterns and auditory-verbal STM span that were observed over the course of NC’s recovery (Martin et al., 1996). As noted, NC initially demonstrated the classic features of deep dysphasia, lexicality and imageability effects and semantic errors in single-word repetition (Martin & Saffran, 1992). His auditory-verbal STM word span was less than one item, whether the span task required a repetition or pointing response. As NC recovered, he no longer made semantic errors in single-word repetition and his word span increased to 2–3 words. This pattern of recovery suggested an association between increased decay rate and rates of semantic errors. A simulation of this pattern in the IA model (Dell & O’Seaghdha, 1992) demonstrated a significant positive correlation between the severity of the decay rate impairment and the presence of semantic errors in repetition.

Martin et al. (1996) proposed that deep dysphasia was a pattern of symptoms that lies on a continuum defined by the severity of impairment of the ability to maintain activation of semantic and phonological representations over the course of processing single- and multiple-word utterances. That ability is controlled in part by the decay rate of activated representations of words. Deep dysphasia is the most severe deficit on this continuum. If decay rate is too rapid, this results in increased imageability and frequency effects and higher rates of phonological, formal and semantic paraphasias in single-word repetition. It is the presence of semantic errors in single-word repetition that distinguishes deep dysphasia

from phonological dysphasia, which otherwise presents with all of the other features of deep dysphasia. In two follow-up studies of NC's recovery, Martin et al. (1996) tested the severity continuum hypothesis by reducing the rate of decay towards normal levels (though still abnormally high). This adjustment in the model parameters led to a pattern of symptoms associated with what eventually would be termed phonological dysphasia (Wilshire & Fisher, 2004).

As a further test of the hypothesis that deep dysphasia lies on a severity continuum, Martin et al. (1996) predicted that adding memory load to a word repetition task would lead to a re-emergence of semantic errors. Memory load was added either by imposing a 5 s delay before a repetition response or by increasing the number of items to be repeated. The result was an increase in error rates overall and an increase in semantic errors. This pattern was simulated with two manipulations of the computer simulation. First, the decay rate was increased, but to a lesser degree than the extremely high rate that led to semantic errors in single-word repetition. Second, performance with this parameter setting was examined at different time steps to simulate the effects of time passage that would happen in the repetition task if a 5 s delay was imposed before responding or if there were two words to be repeated.

On the basis of these behavioural and computer simulation data, Martin et al. (1996) proposed that NC's repetition performance at earlier and later stages of recovery in deep dysphasia could be characterised as two points on a functional severity continuum of a single cognitive ability, maintenance of the activation of semantic and phonological representations in auditory-verbal STM. Furthermore, two variables, auditory-verbal STM span and task demands on that span capacity, should predict the point of breakdown on this severity continuum where semantic errors should appear in the repetition error pattern. If verbal span is severely limited (e.g., less than one word), then semantic errors and imageability effects in single-word repetition should be present. If span capacity is greater than a single item (e.g., 2–3 words), semantic errors should not be present and imageability effects should be reduced in single-word repetition. However, these effects should be observed in repetition of sequences of two or more words, phrases and sentences. This interaction was demonstrated in the study of NC's recovery (Martin et al., 1996), where semantic errors and imageability effects reappeared when a temporal interval was added to a single-word repetition task and when the number of words to be repeated was increased to two. The case study of NC provides evidence that auditory-verbal STM capacity and the size of imageability effect in repetition will interact with the degree to which number of stimuli or delay in response time stresses the limits of verbal span capacity.

As typically observed in deep and phonological dysphasia, NC demonstrated imageability effects in repetition of single and multiple words. That is, high-image (HI) words were repeated more accurately than low-image (LI) words. Martin et al. (1996) accounted for this difference in NC's repetition by assuming (and implementing in the IA model) that HI words have stronger semantic representations than LI words. Martin et al.'s (1996) account of imageability effects in repetition serves as a key theoretical motivation for the treatment tested in this study, which focuses on this one feature that is common to aphasia profiles that fall anywhere on the continuum of deep-phonological dysphasia, difficulty in recognising, comprehending and repeating spoken abstract (LI) words (e.g., Dell, Martin, & Schwartz,

2007; Foygel & Dell, 2000; Hanley, Dell, Kay, & Baron, 2004). If HI and LI words are differentially accessible because HI words have stronger activation levels, it should be possible to improve access to LI words by making them, at least temporarily, higher in imageability. If this in turn facilitates successful access to these words on repeated attempts, they may become easier to access without the facilitating context.

The present study

The purpose of the current study was to investigate an approach to improving LT's ability to access and maintain activation of LI words by creating contexts (adjective-noun phrases) to enhance the imageability of LI words. We sought to determine whether pairing low-image, low-frequency (LI-LF) words in semantically cohesive adjective-noun phrases (e.g., long *distance*; social *exclusion*) would facilitate their repetition in the context of that phrase, and later when presented in word pairs for repetition (e.g., *distance-exclusion*). The imageability effect has been manipulated in some treatments for naming. For example, Kiran, Sandberg, and Abbott (2009) provided evidence that training abstract (LI) words shows greater generalisation to untrained concrete (HI) words than the reverse. This follows the principle of the complexity account of generalisation between trained and untrained items. That is, training more complex (abstract) words will lead to greater generalisation to untrained less complex words (concrete) words (see also Kiran & Thompson, 2003).

In this study, our motivation in manipulating imageability of abstract word stimuli derives from the IA model's assumption of interaction between lexical and semantic levels of word representation. Manipulating imageability of abstract words by narrowing their semantic interpretation in an adjective-noun phrase should make them temporarily more accessible, but importantly, this improved access should carry over to repetition of the LI words without the phrasal context. Our specific predictions include the following:

1. Training repetition of LI-LF nouns in semantically cohesive LI-LF adjective-noun phrases (e.g., long *distance*; social *exclusion*) will improve accuracy of repetition of these same nouns when they are presented as word pairs (e.g., *distance exclusion*).
2. Treatment effects for repetition of LI-LF pairs will be less robust when training repetition of LI-LF adjective-noun phrases that are not semantically cohesive (e.g., *purple agility*).
3. Improvements in repetition of LI-LF pairs will generalise to improvements in repetition of untrained LI-LF pairs.

Method

Participant

History—The participant was LT, a 34-year-old, right-handed, college-educated female. She experienced a left middle cerebral artery infarct involving the left temporal and parietal lobes, and posterior insula in October 2009. LT's employment history included work as a teacher, poet, writer and actress. She was approximately 36 months post onset at the beginning of this study. Prior to participation in the treatment study, LT gave written

informed consent as approved by the Institutional Review Board of Temple University. As per study guidelines, LT passed an audiometric pure-tone, air conduction screening at 25 decibels hearing level (dB HL) at 1K, 2K and 4K Hz bilaterally.

Language evaluation—LT was administered a number of standardised and laboratory-developed assessments to determine aphasia type and language profile. Results can be found in Table 1. Unlike many reported cases of deep-phonological dysphasia (e.g., Howard & Franklin, 1988; Martin & Saffran, 1992), LT presented with minimal impairment of picture naming, scoring 0.85 (51/60) with mainly non-responses and two semantic paraphasias on the long form of the *Boston Naming Test* (BNT; Kaplan, Goodglass, & Weintraub, 1983). To measure auditory comprehension, the complex ideational material subtest of the *Boston Diagnostic Aphasia Examination* (BDAE, Kaplan et al., 1983) was used. LT's pattern of responses on the BDAE revealed decreased accuracy as a function of difficulty of the auditory comprehension task. In contrast, spontaneous language was preserved and was judged as grammatical and free of paraphasias. Although not administered immediately prior to testing, it is notable that LT's aphasia classification according to the *Western Aphasia Battery-Revised* (WAB-R; Kertesz, 2006) was conduction aphasia, with an aphasia quotient (AQ) of 88.6 (88.6/100).

LT's ability to discriminate words from non-words was tested using the *Auditory Lexical Decision Test* (Martin & Saffran, 2002). Her performance was >2 SD above the mean performance of persons with aphasia (PWA) tested in our laboratory on recognition of words $z = 2.67$, $n = 21$, 0.88 ± 0.06 and non-words $z = 2.01$, $n = 21$, 0.91 ± 0.07 , indicating a relatively spared ability to map phonemes onto lexical representations. Lexical comprehension of abstract, concrete and emotional concepts was tested using the *Shallice Test of Abstract, Concrete and Emotional Concepts* (McGill & Shallice, 1978). Here, LT demonstrated a significant advantage in the identification of concrete words compared to abstract words (86% compared to 40%, $p = 0.04$).

Pretreatment cognitive measures—Repetition span subtests of the *Temple Assessment of Language and (Verbal) Short-term Memory in Aphasia* (TALSA, Martin, Kohen, & Kalinyak-Fliszar, 2010) were used to assess digit and word span capacity. Results are reported in Table 2. All span measures reflect serial order recall. For digit span, performance was within 1 SD below the mean performance of PWA tested in our laboratory for pointing $z = -0.59$, $n = 38$, 3.24 ± 1.74 and repetition $z = -0.44$, $n = 38$, 3.54 ± 1.68 .

Measures of verbal span on TALSA subtests provided a refined diagnosis of LT's impairments. LT presented with a moderate-to-severe auditory-verbal repetition deficit influenced by lexicality and imageability effects. Performance was similar on measures of pointing word span, $z = -0.56$, $n = 38$, 2.88 ± 1.21 , and repetition word span $z = -0.50$, $n = 37$, 3.06 ± 1.33 . Word span was over 1 SD below the mean score of PWA within our laboratory $z = -0.96$, $n = 34$, 2.70 ± 1.35 and non-word span was also below average $z = -0.54$, $n = 34$, 1.52 ± 0.95 . When span was varied for imageability and frequency, accuracy was lowest for high-image, low-frequency (HI-LF) words $z = -0.86$, $n = 35$, 2.37 ± 1.21 and LI-LF words $z = -0.70$, $n = 35$, 2.20 ± 1.33 . In word repetition span tasks, errors included semantic and phonological paraphasias and unrelated word errors. On a probe memory span

task that manipulated semantic and phonological characteristics of words in span, LT's semantic span was close to the mean of PWA tested in our laboratory, $z = -0.21$, $n = 34$, 3.44 ± 1.52 . Probe memory phonological span was an area of strength, with LT scoring over 2 SD above the mean, $z = 1.52$, $n = 34$, 3.80 ± 2.04 .

Pretreatment evaluation of functional communication—The *Communicative Effectiveness Index* (CETI; Lomas et al., 1989) was used to quantify LT's and her primary caregiver's (mother) perception of functional communication abilities before and after her stroke on a 1–10 scale. Both individuals demonstrated agreement in rating various aspects of communication requiring intact auditory processing as poor to fair (range 3–7; mean = 4.5). This index provided functional examples of the impact of her aphasia on everyday living. Conversational situations noted to be difficult for her included initiation, participation, spontaneous topic change, fast pace of speech and multiple conversational partners.

Experimental stimuli

Stimuli were selected from a corpus of words that varied in frequency and imageability (assembled in the Aphasia Rehabilitation Research Laboratory at Temple). The stimuli consisted of 30 LI-LF noun pairs that were 4–6 syllables in length. Words in pairs were neither semantically nor phonologically related. Frequency and imageability ratings were verified through use of the MRC Psycholinguistic database (Wilson, 1988). Three sets of HI-HF noun pairs, 10 pairs per set, were assembled and assigned to two treatment conditions and a response generalisation condition:

Set 1 (treatment 1, TX1): “semantically + syntactically cohesive” (SEM + SYN) adjective-noun phrases (e.g., high rating).

Set 2 (treatment 2, TX2): “syntactic only” (SYN only) adjective-noun phrases that are not semantically cohesive (e.g., purple agility).

Set 3 (response Generalisation): “limited exposure” condition including 10 noun pairs to assess response generalisation.

Selection of adjectives for the adjective-noun phrases followed the procedures and criteria for selection of the nouns.

Experimental design

A single-subject multiple baseline, multiple probe design was used to analyse acquisition, maintenance, follow-up and generalisation effects of treatment. The dependent variable was accuracy of repetition of LI-LF pairs in probes.

Baseline phase—During the baseline phase, the 30 LI-LF noun pairs were continuously measured in probes in randomised order with no visual support until a stable baseline was achieved. We defined a stable baseline as no more than 0.20 variability between two consecutive probes within three consecutive trials, a moderately conservative criterion used by Wambaugh, Cameron, Kalinyak-Fliszar, Nessler, and Wright (2004) and others (Kiran et al., 2013; Wambaugh & Ferguson, 2007).

Acquisition phase—During the acquisition phase of TX1, set 1 probes identical to those in baseline were administered prior to the start of each treatment session in randomised order, while LI-LF pairs in set 2 (for TX2) were maintained in baseline at a reduced probing schedule, every other probe session. The LI-LF pairs in set 3, the limited exposure set, were probed every fourth session to assess response generalisation. At the conclusion of the acquisition phase for TX1, the probing schedule was switched so that set 2 items (TX2) were continuously probed and LI-LF pairs in set 1 (TX1 Items) were probed every other probe session in maintenance. Criterion for acquisition of LI-LF pairs was 0.80 correct across two consecutive probes.

Maintenance and follow-up phase—Set 1 LI-LF noun pairs were probed every other probe session in maintenance. Follow-up probes for TX1, TX2 and response generalisation conditions were administered 3, 6 and 8 weeks following the end of all treatment.

Interim and post-treatment assessment—Pretreatment language evaluations were readministered between treatment conditions. At the completion of treatment, subtests from the TALSA were readministered.

Treatment

An implicit priming protocol was used. Adjective-noun phrase primes (e.g., “high rating and common fallacy”) were presented three times for repetition for each LI-LF noun in each pair (for a total of six phrase primes). A treatment session included the repetition of 60 phrase primes in total. Following repetition of the target primes, the target LI-LF word pair (e.g., rating, fallacy) was presented for repetition, 10 repetitions of LI-LF word pairs occurred within one session. The treatment programme consisted of two treatment conditions:

1. Treatment condition 1 (TX1; SEM + SYN). LF-LI nouns in pairs from set 1 were combined with adjectives to form semantically cohesive adjective-noun phrases (e.g., long *distance*; social *exclusion*) to be used as primes for the LI-LF pair targets (e.g., *distance-exclusion*).
2. Treatment condition 2 (TX2; SYN only). Adjective-noun phrases were formed from LI-LF pairs in set 2 for use as primes. Adjective-noun phrases were not semantically cohesive (e.g., purple *agility*).

The order of presentation of the phrase primes for each noun in the pair was alternated across treatment sessions using an ABBA design (e.g., treatment session 1: AB– “high rating” followed by “common fallacy”; treatment session 2: BA– “common fallacy” followed by “high rating”; treatment session 3: AB– “high rating” followed by “common fallacy”, and so on). Sessions were two times per week and lasted from 45 to 60 min in duration, and included repetition of 10–30 LI-LF probes followed by the treatment which required a total repetition of 60 LI-LF adjective-noun pairs. Appendix provides an example of the treatment protocol.

Reliability

Reliability and procedural fidelity measures were employed throughout all conditions. Primary observers were licensed speech and language pathologists and secondary observers

were laboratory research assistants, all working in the Aphasia Rehabilitation Research Laboratory. All observers were trained in data collection protocol and proper response coding and provided with operational definitions to support these procedures. Primary observers handwrote all participant responses in real time using a pre-constructed checklist, and all sessions were audio-recorded. Inter-rater reliability was established through the use of independent secondary observers present in real time within the session and the use of audio recordings. Independently written transcriptions by a secondary observer within the treatment room were collected in 15 of 40 sessions across conditions. The result was 1.00 agreement between examiners. Following all sessions, a secondary observer listened and re-transcribed responses that were audio-recorded in probe testing, with 1.00 (770/770 items) agreement with the other examiners.

Effect sizes

As an estimate of the strength of treatment effects in each condition, we calculated effect sizes according to the guidelines of Beeson and Robey (2006). For TX1 and TX2, effect sizes were calculated for treatment effects using the mean of all baseline probes and the mean of last three treatment probes. They were also calculated for follow-up effects using the mean of all baseline probes and the mean of the three follow-up probes. Although there are currently no standards for evaluating the significance of effect sizes for repetition treatment, we can evaluate the relative size of treatment effects for TX1 (semantically cohesive adjective-noun phrases) and TX2 (adjective-noun phrases that are not semantically cohesive).

Results

The proportions of LI-LF pairs repeated correctly in probes during each treatment condition and in all phases of treatment are shown in Figure 3.

Baseline

LT demonstrated stable repetition performance across TX1, TX2 and response generalisation probes prior to the beginning of treatment, as defined by 0.20 accuracy across three sessions for all three conditions. By baseline session 10, LT's proportion correct of stimuli was within 0.20 across baselines 8, 9 and 10. Across these sessions, proportion correct of TX1 stimuli averaged 0.25, proportion correct of TX2 stimuli averaged 0.30 and proportion correct of response generalisation stimuli averaged 0.55. Her level of performance met our criterion for baseline stability across all conditions.

Acquisition effects

TX1 condition—LT's proportion of correct repetitions of LI-LF pairs in probes demonstrated steady improvement. LT's ability to repeat treatment word pairs during probe testing increased by 0.70 in TX1 and behavioural criterion was met by probe 10.

TX2 condition—Baseline testing was extended before application of treatment to set 2 LI-LF pairs to reestablish stable accuracy levels. Four baseline probes were conducted, resulting in mean repetition performance of 0.45, which was a 0.19 increase from baseline

performance levels. Despite this modest increase, LT's proportion of correct repetitions of LI-LF pairs in probe testing was variable and behavioural criterion was not met.

Given LT's variable performance during the TX2 condition, we decided to implement a semi-replication of the TX1 condition using the stimuli from TX2. We created semantically cohesive adjective-noun phrases for each TX2 LI-LF word. Unexpectedly, in baseline testing, LT reached criterion on repetition of the noun pairs by the third baseline probe. Thus, there was no need to continue this attempt at replication of the SEM + SYN treatment. Although not shown in Figure 3, these data were obtained following the end of TX2 and before the first follow-up probe, 3 weeks after the last TX2 probe.

Response generalisation condition—Accuracy for the response generalisation stimuli remained in the baseline range with no evident improvement.

Maintenance

During TX2, effects of TX1 remained above baseline levels but below final acquisition levels.

Follow-up

All probes were administered 3, 6 and 8 weeks following the end of our TX2 condition. Thus, TX1 ended approximately 15 weeks prior to the final all probe. Despite this lapse in time following TX1, accuracy levels for these pairs remained at the same behavioural criterion level as the last probe within the treatment condition during the 3-week follow-up probe. Accuracy then declined by 0.20 in subsequent follow-up probes, resulting in mean repetition performance of 0.80. Accuracy for the TX2 stimuli was variable, as it was during treatment. No change in accuracy for response generalisation stimuli was observed.

Effect sizes

Effect sizes are reported in Table 3. The treatment effect size for TX1 is more than two times the effect size for TX2, indicating that semantic coherence of the adjective-noun phrase is a key ingredient of the priming effect of the adjective-noun phrases. Effect sizes in the follow-up phase are lower than in the treatment phase, but the effect size for TX1 is greater than TX2.

Interim and post-treatment tests of language and STM abilities

Language interim treatment testing—During the conduction of baseline testing between TX1 and TX2, some interim language evaluations were readministered. Results of these tests are reported in Table 1. LT's pretreatment performance on a test of *Auditory Lexical Decision* (Martin & Saffran, 2002) was within normal range and did not require re-administration. Lexical comprehension of abstract, concrete and emotional concepts using the *Shallice Test of Abstract, Concrete and Emotional Concepts* (McGill & Shallice, 1978) revealed a small increase in accuracy for abstract words. LT demonstrated improved auditory comprehension on the complex ideational material subtest of the BDAE (Kaplan et al., 1983), with a 0.16 increase in accuracy. Picture naming improved by 0.10 on the BNT (Kaplan et al., 1983). Although not administered immediately prior to treatment, the post-

treatment aphasia quotient for LT according to the *WAB-R* (Kertesz, 2006) improved six points, from 88.6 to 94.5. This is notable because LT's post-treatment aphasia classification as measured by the aphasia quotient changed from a diagnosis of conduction aphasia to normal or non-aphasic.

Post-treatment cognitive measures—Performance on repetition span subtests of the TALSA (Martin et al., 2010) following treatment are reported in Table 2. Most notable, for repetition of digit span, performance was improved over 1 SD above the mean performance of PWA, from a span of 2.80 to a span of 4.20. For repetition of words, LT also demonstrated an increase in accuracy with performance falling just under mean performance of PWA in our laboratory. Performance on probe memory spans manipulating semantic and phonological characteristics revealed modest improvements in accuracy on each span. Results on other measures of span were unremarkable.

Post-treatment psychometric evaluation of functional communication—The CETI (Lomas et al., 1989) was administered after post-testing to determine LT's and her mother's perception of functional communications. LT's mother's ratings of functional communication improved across categories, demonstrating an overall increase of 0.23. Most notably, LT's responses increased to 10.0, reporting that she perceived her functional communication abilities across categories to be as efficient as they were before her stroke. Anecdotally, LT and her mother reported that following the conclusion of the treatment study LT felt comfortable speaking on the telephone, as opposed to alternative means of visual electronic communication.

Discussion

The purpose of this study was to examine a treatment paradigm developed to improve repetition of LI-LF words and improve auditory-verbal STM capacity in a case of phonological dysphasia. Difficulty with recognition, comprehension and repetition of LI-LF words has been established in numerous case studies of deep-phonological dysphasia (e.g., Howard & Franklin, 1988; Martin et al., 1994; Wilshire & Fisher, 2004). Martin et al. (1996) have attributed this to an impairment in activating and maintaining activation of the semantic representations of LI-LF words. Our investigation offers a theoretically motivated rehabilitation approach that targets the repetition impairment in phonological dysphasia by enriching the semantic context of LI-LF noun pairs. We predicted that adding semantic context (in the form of adjective-noun phrases) to each word in the LI-LF pair would facilitate access to and maintenance of LI-LF word pairs when the semantic context was removed and the LI-LF words were repeated in isolation.

Our protocol showed that when semantically cohesive adjective-noun phrases were used as primes, LT's repetition of LI-LF word pairs in probes improved steadily and robustly during the acquisition phase and was maintained above baseline levels during maintenance and follow-up. This was not the case when adjective-noun phrases that lacked semantic cohesion were used as primes. LT's ability to repeat LI-LF pairs in probes in that condition showed variable performance and by follow-up, repetition performance declined to baseline levels. These results support the hypothesis that feedback activation from the semantic network

strengthens the lexical and phonological representations of words and that increasing the strength of that semantic feedback activation improves access to LI words. For this participant, we found that this strategy facilitated immediate access to the words in the context of the adjective-noun phrases and generalised to isolated repetition in probes.

This intervention also had a positive effect on auditory-verbal STM capacity, as evidenced by generalised improvements in post-testing measures including digit span and word span. We attribute the increases in verbal span to improved access to word representations, which can result from improvement of one or both parameters that mediate spreading activation, connection strength and decay rate. Thus, embedding hard-to-access LI words in more imageable adjective-noun phrases improves activation and short-term maintenance of semantic representations of words. These improvements should be evident in greater accuracy in repetition of words as well as an increase in verbal span capacity. In addition to the improvement observed in verbal span tasks after treatment, LT's repetition of noun pairs used in the treatment study also improved from 0.20 correct on the first baseline probe to 0.70 correct during the last follow-up probe in TX1, the SEM + SYN condition. Thus, STM span for LI words increased following this intervention.

The present study aimed to develop a treatment to strengthen access to LI-LF words and thereby improve repetition of these words. The theoretical framework of the IA model of language processing and repetition in aphasia (Martin et al., 1994; Martin & Saffran, 1997) motivated our predictions for this treatment approach, and in turn, served as a means by which our results could be understood. Repetition of words in an IA model is mediated by input phonological activation of the word form in the lexicon and feedback activation from semantics, which together converge on lexical nodes (the target word and competitors) in the lexical network. HI words benefit more from stronger top-down semantic feedback activation than LI words. This accounts for imageability effects in word repetition. In this study, manipulation of the linguistic context of an adjective-noun phrase influenced LT's ability to activate and maintain activation of the phonological forms of these LI words. Access was facilitated by embedding the LI words in a context that increases imageability and the strength of semantic feedback to the lexical form of the word. This feedback increased the number of opportunities for successful activation of the word form in the lexicon, contributing to generalisation of access to the LI-LF words without the semantically enriched context.

This study presents one of the first treatment approaches targeting the repetition impairment in deep-phonological dysphasia, extending the literature base beyond characterising the nature of the impairment. Outcomes of this study demonstrate two important potentials of this intervention. First, the view of aphasia as an impairment of processing that affects access to otherwise intact representations of words opens up a new way of thinking about treatment approaches. Following the principles and specific components of a model that embraces this view can guide development of treatment protocols designed to improve the strength and stability of activation processes and thereby improve access to representations in repetition. Second, dynamic models that focus on aphasia as an impairment of processing demonstrate that cognitive plasticity is feasible, providing the guidelines to stimulate cognitive changes. The notion of cognitive plasticity is akin to neural plasticity. Evidence for

the latter comes in the form of neural changes (e.g., increased or decreased neural activity) observed in imaging studies before and after treatment (Fridriksson, 2011; Fridriksson, Richardson, Fillmore, & Cai, 2012; Sandberg, Bohland, & Kiran, 2015; Sandberg & Kiran, 2014).

At the cognitive-behavioural level, behavioural treatments designed on the basis of cognitive models can result in measurable changes in performance that reflect cognitive plasticity. These changes may or may not be manifested in neurological changes. It may be ideal to observe both neural and cognitive changes following treatment, and ideally, rehabilitation research should assess both of these levels of change. However, for clinical purposes, the measures of cognitive change are the most direct and immediate measures of change that reflect better language function. In this study, we have provided an example of the use of principles of cognitive plasticity, theoretically supported by the IA model. We applied these principles to develop and implement a treatment protocol that improved better auditory access to a class of words that are predicted by the model to be difficult to access. The success of this cognitive-based theory-guided treatment supports the usefulness of this approach to development of treatment paradigms to promote comprehensive recovery of language abilities in aphasia.

Clinical relevance

Our results directly inform clinical practice, offering a theoretically motivated approach to an essential component of functional communication. There are countless real-life situations where repetition and auditory-verbal STM capacity are essential for communicative success. For individuals with these impairments, daily activities such as conversing via telephone could be unmanageable. If the conversational context does not provide the necessary level of semantic support, abstract words may be difficult to process and repeat. An example of this could be receiving a call from a doctor's office regarding a change in medication. The explanation "adjustment of oral medication will avoid a hypertensive crisis" contains many abstract words and could be misunderstood by an individual with difficulty accessing LI words. The results of this study indicate that treatments which repeatedly facilitate successful attempts to access a lexical word form can potentially improve ease of access to that word without facilitation. This can result in improved performance on measures of language and cognition as well as measures of functional communication in day-to-day activities.

Future directions

There is a paucity of evidence available on the deep to phonological dysphasia continuum (i.e., <30 studies) and less evidence for treatment of this disorder. This treatment to improve access to and short-term maintenance of abstract word pairs was successful in the treatment of repetition and auditory-verbal STM in this case. The evolution of LT's language profile from deep to phonological dysphasia suggests that the treatment paradigm may be extended to other individuals whose word processing deficits fall somewhere along the deep-phonological dysphasia severity continuum. Thus, it would be of interest to test this treatment approach with other participants with repetition and auditory-verbal STM impairments along this severity continuum. For example, individuals at less severe points on

the deep-phonological dysphasia continuum may be able to repeat word pairs accurately regardless of their imageability, but would show the imageability effects and semantic errors in repetition of three-word sequences or sentences. In these cases, treatment would be adjusted to include more difficult stimuli for repetition that would push the limits of auditory-verbal STM capacity and through the procedural protocol used in this study, gradually improve the ability to access and maintain activation of longer word sequences and sentences.

In addition to applying the principles of this treatment to individuals at various points along the severity continuum of deep-phonological dysphasia, we will also explore ways to strengthen generalisation of treatment effects. Using a variety of adjectives in the adjective-noun phrases could increase the likelihood of generalisation to untrained stimuli. For example, the noun “habit” could be paired with multiple adjectives in phrases that vary in length and complexity (e.g., new habit; daily habit; creature of habit; break the habit). It is possible that embedding a difficult-to-access LI word in a variety of semantically enriching contexts would stimulate stronger and more sustained semantic activation. Improvement in repetition of LI-LF pairs would not be linked to a single specific adjective, and in that case, could promote greater response generalisation to untrained LI-LF pairs.

We add one final note about the generalisability of this treatment protocol. This approach is appropriate for someone whose repetition and maintenance of words in auditory-verbal STM relies primarily on activation and short-term maintenance of semantic representations of words, relative to the ability to activate and maintain activation of phonological representations. There are individuals with aphasia who show a somewhat opposite difficulty in repetition, poor access and maintenance of semantic representations of words relative to phonological representations. In theory, these individuals should demonstrate a reduced imageability effect in repetition as recall will be based primarily on the phonological activation of words with little feedback from semantic support. This reliance on phonological activation would likely lead to a reduced auditory-verbal repetition span, but with errors that are more phonologically than semantically related. This pattern has been observed in some studies (e.g., Martin & Saffran, 1997) but remains to be tested more fully.

Conclusion

We have presented a treatment approach that is intended to improve access and short-term maintenance of LI (abstract) word pairs in repetition. This treatment was used in a case of a person whose repetition pattern is characteristic of deep-phonological dysphasia. The treatment is theoretically motivated by an IA model of word processing that assumes interactivity among levels of word representation over the course of recognising, comprehending, repeating and producing words. This treatment was successful for our participant who presented with phonological dysphasia, which evolved from an initial diagnosis of deep dysphasia. The treatment approach exemplifies the potential value in manipulating linguistic characteristics of stimuli in ways that improve access between phonological and lexical-semantic levels of representation and provides an example of ways in which cognitive models of word processing can be used to guide treatment for aphasia.

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Appendix

Treatment conditions: sample stimuli with instructions for administration

Protocol: Adjective-noun phrases were repeated three times and sessions followed an ABBA design, alternating AB and BA by session. Followed by a single repetition of the abstract noun pair, order of presentation was constant across sessions. In one treatment session, adjective-noun phrases were produced 60 times and abstract noun pairs were produced a total of 10 times.

1. Treatment condition 1: modifier adjective-noun phrases (TX1; SEM + SYN)

Examiner: “You will hear two words in a phrase. After you hear the phrase, repeat exactly as you heard the words. You will have *three* attempts for each phrase”.

Sessions 1, 3, 5, 7, 9- AB

Adjective-noun phrase 1—A	Adjective-noun phrase 1—B
NATIONAL TRAGEDY	ELECTRICAL CIRCUIT
NATIONAL TRAGEDY	ELECTRICAL CIRCUIT
NATIONAL TRAGEDY	ELECTRICAL CIRCUIT

Sessions 2, 4, 6, 8, 10—BA

Adjective-noun phrase 2—B	Adjective-noun phrase 2—A
ELECTRICAL CIRCUIT	NATIONAL TRAGEDY
ELECTRICAL CIRCUIT	NATIONAL TRAGEDY
ELECTRICAL CIRCUIT	NATIONAL TRAGEDY

Sessions 1–10

Noun pair

Examiner: “Now you will hear *two* words. Repeat the words exactly as you heard them”.

TRAGEDY CIRCUIT

2. Treatment condition 2: syntactic only adjective-noun phrases (TX2; SYN)

Examiner: “You will hear two words in a phrase. After you hear the phrase, repeat exactly as you heard the words. You will have *three* attempts for each phrase”.

Sessions 1, 3, 5, 7, 9—AB

Adjective-noun phrase 1—A	Adjective-noun phrase 1—B
TASTELESS INFECTION	AVERAGE FRICTION
TASTELESS INFECTION	AVERAGE FRICTION
TASTELESS INFECTION	AVERAGE FRICTION

Sessions 2, 4, 6, 8, 10—BA

Adjective-noun phrase 2—B	Adjective-noun phrase 2—A
AVERAGE FRICTION	TASTELESS INFECTION
AVERAGE FRICTION	TASTELESS INFECTION
AVERAGE FRICTION	TASTELESS INFECTION

Sessions 1–10

Noun pair

Examiner: “Now you will hear two words. Repeat the words exactly as you heard them”.
INFECTION FRICTION

Figure 1. Lexical network structure in the spreading activation production model (Dell & O'Seaghdha, 1992).

Figure 2.
An interactive activation model of single-word repetition (Martin et al., 1994).

Figure 3. Proportion correct on LI-LF probe trials in for SYN + SEM, SYN only and limited exposure treatment conditions and in all phases of treatment.

Table 1

LT's performance on standardised language evaluations pre- and interim treatment: proportion correct.

Measure	Pretreatment	Interim
<i>Boston Naming Test</i> ¹ ($n = 60$)	0.85	0.95
<i>Boston Diagnostic Aphasia Evaluation</i> ²		
Complex ideational material ($n = 12$)	0.67	0.83
<i>Auditory lexical decision</i> ³		
Words ($n = 40$)	0.93	
Non-words ($n = 40$)	1.00	
<i>Shallice Test of Abstract, Concrete and Emotional Concepts</i> ⁴		
Abstract ($n = 30$)	0.40	0.50
Concrete ($n = 30$)	0.86	0.80
Emotional ($n = 15$)	0.73	0.80

¹Kaplan et al. (1983) proportion correct.

²Goodglass and Kaplan (1983) proportion correct.

³Martin, Schwartz, and Kohen (2006) proportion correct.

⁴McGill and Shallice (1978) proportion correct.

Table 2

LT's pre- and post-treatment performance on TALSA span measures (serial order recall) with language variations.

	Pre	Post
<i>Digit and word span¹</i>		
<i>Digits (ISO)</i>		
Pointing	2.20	2.60
Repetition	2.80	4.20
<i>Words (ISO)</i>		
Pointing	2.20	2.40
Repetition	2.40	3.20
<i>Word and non-word repetition span²</i>		
Word	1.40	1.20
Non-word	1.00	1.00
<i>Repetition span for words varied for frequency (F) and imageability (I)³</i>		
HI-HF	2.67	2.33
LI-HF	1.67	1.00
HI-LF	1.33	2.00
LI-LF	1.33	1.33
<i>Probe memory span⁴</i>		
Semantic	3.12	4.00
Phonological	6.56	6.76

¹Maximum string length = 7 items.

²Maximum string length = 5 items.

³Maximum string length = 5 items.

⁴Maximum string length = 7 items.

HI-HF: high-image, high-frequency; LI-HF: low-image, high-frequency

HI-LF: high-image, low-frequency; LI-LF: low-image, low-frequency.

Table 3

Effect sizes for treatment and maintenance phrases of treatment 1 and treatment 2.

Condition	Treatment	Follow-up
Treatment condition 1: <i>SYM + SYN</i>	5.80	3.92
Treatment condition 2: <i>SYN only</i>	2.77	2.16