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Research Article

# Masked Repetition Priming Treatment for Anomia

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**Purpose:** Masked priming has been suggested as a way to directly target implicit lexical retrieval processes in aphasia. This study was designed to investigate repeated use of masked repetition priming to improve picture naming in individuals with anomia due to aphasia.
**Method:** A single-subject, multiple-baseline design was used across 6 people with aphasia. Training involved repeated exposure to pictures that were paired with masked identity primes or sham primes. Two semantic categories were trained in series for each participant. Analyses assessed treatment effects, generalization within and across semantic categories, and effects on broader language skills, immediately and 3 months after treatment.
**Results:** Four of the 6 participants improved in naming trained items immediately after treatment. Improvements were generally greater for items that were presented in training with masked identity primes than items that were presented repeatedly during training with masked sham primes. Generalization within and across semantic categories was limited. Generalization to broader language skills was inconsistent.
**Conclusion:** Masked repetition priming may improve naming for some individuals with anomia due to aphasia. A number of methodological and theoretical insights into further development of this treatment approach are discussed.

Anomia is one of the most pervasive and disruptive symptoms of aphasia, negatively influencing a person's ability to communicate across modalities. Evidence suggests that individuals with aphasia often retain the ability to process language information implicitly even when they are unable to demonstrate this language knowledge explicitly (e.g., Hagoort, 1993; Mimura, Goodglass, & Milberg, 1996; Revonsuo, 1995; Revonsuo & Laine, 1996; Roberts, Lambon Ralph, & Woollams, 2010). In anomia, this may be manifested in the ability to retrieve syntactic and partial word form information even if the speaker cannot retrieve the word itself (e.g., Badecker, Miozzo, & Zanuttini, 1995; Goodglass, Kaplan, Weintraub, & Ackerman, 1976; Macoir & Beland, 2004; Vigliocco, Vinson, Martin, & Garrett, 1999). This paradox has led to the conclusion that word retrieval impairments in aphasia are due to problems with retrieval processes rather than language representations having been lost (e.g., McNeil, Odell, & Tseng, 1991).

These retrieval processes, such as spreading of activation within the language networks, maintenance of activation, and attention allocation, are difficult to understand, assess, and treat because they are largely implicit; that is, they are unconscious and outside volitional control. Because of these difficulties, most available anomia treatments focus on explicit linguistic awareness and tasks (e.g., semantic feature analysis and phonomotor therapy; Boyle, 2004, 2010; Boyle & Coelho, 1995; Kendall, Oelke, Brookshire, & Nadeau, 2015; Kendall et al., 2008) but do not attempt to target the implicit processes that are so critical for language. This difference between the types of processes needed for accurate, efficient language use and available treatment methods for anomia suggests that it may be appropriate to develop treatments that focus more directly on implicit language processes, either to capitalize on them if they are intact or to attempt to repair them if they are impaired (e.g., Ferrill, Love, Walenski, & Shapiro, 2012; Prather, 1994; Prather, Zurif, Love, & Brownell, 1997; Prather, Zurif, Stern, & Rosen, 1992; Silkes & Rogers, 2012).

One approach that has been used to tap directly into implicit processes in aphasia is masked repetition priming. This method involves repeatedly presenting the names of target pictures as prime words before presenting the pictures. Those prime words are masked, through a very rapid presentation rate and the presence of competing visual stimuli, to reduce the viewer's conscious awareness of them (Forster, Mohan, & Hector, 2003). By minimizing conscious awareness of the primes, the lexical networks can be activated

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and engaged in a bottom–up fashion to strengthen network connections through Hebbian learning (Hebb, 1949), rather than being influenced by top–down attempts to process the stimulus that can often interfere with accuracy. Using this approach, the masked primes are intended to preactivate the appropriate implicit lexical representation so that the target word is more readily available when an explicit response is required. The relevant mechanisms can be explained by network models of lexical processing. Within the context of an interactive activation model of language (Dell, 1986; Dell & O'Seaghdha, 1992), the early activation of orthographic forms automatically spreads activation to lexical forms, bringing them closer to threshold when the time for retrieval arrives. Within the context of a parallel distributed processing model of language (Nadeau, 2001), early activation of orthographic forms automatically engages the entire lexical network associated with the target item, giving the network a temporal advantage for activating and recognizing the appropriate neural assembly for the target word.

The potential to use masked primes to facilitate word retrieval in anomia was first demonstrated in principle in a single individual with anomia due to a cavernous angioma (Avila, Lambon Ralph, Parcet, Geffner, & Gonzalez-Darder, 2001). In this early study, the participant was asked to name pictures, half of which were preceded by the written picture name, masked to prevent conscious reading of the word. Each picture was shown only once in each session, with primes presented one time for each primed picture. The participant was more accurate overall in naming primed than unprimed words.

This finding of immediate masked priming effects in aphasia prompted the question of whether repeated exposure to masked primes over multiple sessions might lead to lasting changes in naming accuracy. After determining a likely appropriate interval between masked primes and target pictures (Silkes, Dierkes, & Kendall, 2013; Silkes & Rogers, 2012), this question was addressed with four participants with poststroke aphasia, finding overall positive responses to treatment (Silkes, 2015).

The single-subject, multiple-baseline study reported here continues to explore the effects of a multisession masked repetition priming training paradigm on naming of trained and untrained pictures (within and between semantic categories) and effects on broader measures of language. With six participants with poststroke aphasia, each analyzed and reported independently, this study investigated whether training word retrieval using masked primes would lead to improved naming of trained items, semantically related items, and semantically unrelated items. In addition, this study investigated whether training word retrieval using masked primes would have any effect on broader language function beyond the experimental naming probes.

## Method

All procedures were approved by the University of Washington Institutional Review Board. Informed consent was obtained from all participants through a multimodal conversation to make the process and information accessible for people with aphasia.

### *Participants*

Six participants with aphasia completed this single-subject, multiple-baseline protocol (see Table 1 for demographic information). All participants had aphasia with anomia, as documented by performance on the Western Aphasia Battery (WAB; Kertesz, 1982) and the Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 2001). All had intact single-word reading comprehension, as documented by the first four subtests of the Reading Comprehension Battery for Aphasia (LaPointe & Horner, 1979), and no evidence of right-hemisphere impairment, with intact nonlinguistic problem solving as documented by Raven's Coloured Progressive Matrices (Raven, 1976). No participants had more than mild apraxia of speech or dysarthria, as shown by performance on a speech motor screening adapted from Duffy (2013) and absence of clinical evidence of speech motor production impairments impacting participation in treatment tasks. Vision was normal or corrected to normal, as verified with a Tumbling E Eye Chart and line bisection test. None reported any history of developmental speech or language problems (including dyslexia or other reading problems) after the age of 8 years.

### *Setting and Equipment*

All sessions were held in a quiet room. Headphones were provided on request to serve as ear muffs if participants found intermittent noise from outside the room to be distracting. All naming probes and training stimuli were presented via E-Prime Professional 2.0 (Version 2.0.10.212; Psychology Software Tools) on a PC running Windows 7, with a 20-in. CRT computer screen set to a refresh rate of 70 or 100 Hz to maximize millisecond accuracy for each participant's prime exposure duration. Responses were made verbally and recorded (Olympus Digital Voice Recorder VN-4100PC) for later scoring reliability and response time measurement. Time measurements were made manually using the visual display capacity in Audacity (Mazzoni & Dannenberg, 2002).

### *Stimuli*

Target stimuli were picturable nouns in 14 semantic categories (see Table 2). Category members spanned a range of word length, typicality, and word frequency, and all were determined to be logical members of their assigned category by the author and members of the University of Washington Aphasia Research Laboratory.

Picture stimuli used in testing and treatment were color photographs that contained no relevant written information (e.g., the words "school bus" were removed from that picture). Stimulus lists were individually created for each participant (see details of this process below and final lists in Appendices A–F).

**Table 1.** Participant demographic information and initial test scores.

| ID | Gender | Age | Diagnosis | Time postonset | WAB | BNT | RCPM | RCBA | % CIUs | CIUs per min |
|---|---|---|---|---|---|---|---|---|---|---|
| PN | F | 64 | Left parenchymal hemorrhage in the basal ganglia, extending into the intraventricular space | 31 months | 90.8 | 42 | 30 | 30 | 78.18 | 68.79 |
| PP | M | 78 | Left embolic CVA | 11 years | 81.6 | 46 | 33 | 30 | 73.43 | 141.22 |
| PR | M | 65 | Subarachnoid hemorrhage due to an aneurysm in the left middle cerebral artery | 14 years | 28.4 | 2 | 29 | 26 | 67.19 | 93.73 |
| PS | M | 62 | Left CVA with extension through the frontal, temporal, and parietal lobes and into the left basal ganglia and insula and subinsular regions | 5 years | 54.0 | 19 | 30 | 29 | 67.05 | 74.60 |
| PU | F | 66 | Left CVA involving the posterior division of the left MCA, including involvement of three fourths of the left anterior temporal lobe, the superior temporal gyrus, the posterior insula, and inferior parietal cortex | 12 months | 77.2 | 31 | 32 | 30 | 68.23 | 85.13 |
| PV | M | 55 | Left CVA; mild apraxia of speech with occasional sound distortions | 11 years | 88.4 | 43 | 34 | 30 | 81.78 | 114.77 |

*Note.* BNT = Boston Naming Test; CIUs = correct information units; CVA = cerebrovascular accident; F = female; M = male; MCA = middle cerebral artery; PN = Participant N; PP = Participant P; PR = Participant R; PS = Participant S; PU = Participant U; PV = Participant V; RCBA = Reading Comprehension Battery for Aphasia; RCPM = Raven's Coloured Progressive Matrices; WAB = Western Aphasia Battery.

Prime words that preceded pictures in the treatment protocol were either identity primes (i.e., the name of the upcoming picture) or sham primes (i.e., strings of *x*s and *g*s of the same length as the name of the target item). All primes were presented in 30-point, black, Arial font centered on the computer screen.

Word frequency counts were taken from the SUBTLEX database (Brysbaert & New, 2009) for single words and were calculated from the Corpus of Contemporary American English database (Davies, 2008) for multiword items and proper names. An online probability calculator (Vitevitch, Armbruster, & Chu, 2004) was used to determine phonotactic probabilities.

**Table 2.** Semantic categories presented to participants as options for treatment.

| |
|---|
| Animals |
| Body parts |
| Household items |
| Instruments |
| Occupations |
| Produce |
| Sports and games |
| Things to wear |
| Tools |
| Toys |
| Vehicles |
| Famous people |
| Brands and logos |
| Gardening |

*Note.* For some higher-level participants, the only category that yielded enough items was "famous people," which was then subdivided into people involved in entertainment (e.g., actors, musicians, producers, directors) and "other" (e.g., politicians, athletes, and infamous or historical figures).

## *Procedures*

Experimental and data processing procedures, and most analysis procedures, were the same as those reported previously (Silkes, 2015) and are briefly summarized here.

### Stimulus Selection

After initial testing was completed to determine that participants qualified to be included in the study, three semantic categories were chosen for initial baseline testing. To do this, participants were first shown the list of 14 semantic categories and asked to choose three categories for which they thought they would have difficulty naming pictures.

Once three potential semantic categories were identified, baseline naming probes were administered for each of those categories. Naming probes involved participants naming pictures presented one at a time on the computer screen. The baseline naming probes were conducted on at least three semantic categories with the goal of identifying two on which performance was low enough to be included in the treatment protocol. Probe lists were blocked by semantic category, with a random order of presentation within each list. Lists that were clearly too easy for a participant were removed from baseline testing and replaced with another category until two appropriate categories were identified. Seven baseline probes were administered across 4 days for each category selected for treatment. As each participant completed baseline testing, they were asked to report whether each stimulus they failed to name accurately was familiar or not; only items that they reported were familiar were included in the final stimulus lists.

After identifying two semantic categories for treatment, specific items were identified that had been named correctly three times or fewer during baseline probes and not during the last baseline probe. From these, 24–30 were chosen, and each was assigned to one of the three conditions: (a) Trained (T) items were presented repeatedly in treatment sessions with masked identity primes, (b) untrained–exposed (UE) items were presented repeatedly in treatment sessions with masked sham primes, and (c) untrained–unexposed (UU) items were presented only during baseline, posttreatment, and maintenance probes and not seen during treatment sessions or treatment probes. Words were balanced across all three conditions for word frequency, number of letters, number of phonemes, and phonotactic probability, and closely related items (e.g., presidents or newscasters) were distributed across conditions. Each condition had the same number of items, although the number of items per condition varied between participants and sometimes between training lists for the two semantic categories for the same participant, based on the number of available stimulus items.

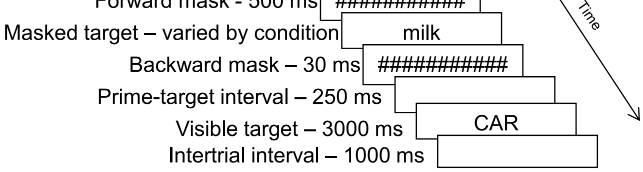
**Prime Visibility Threshold Testing**

Before treatment began for the first semantic category list (L1), participants were tested to establish the prime exposure duration at which they were unable to reliably obtain task-relevant information from the masked primes (Reingold, 2004). Testing involved a category judgment task, in which participants indicated whether either of the words presented in each stimulus pair (one masked and one unmasked) was something to eat or drink (see Figure 1 for a sample trial). Initial training trials were conducted with masked words presented at long-enough exposure durations (300 and 100 ms) that they were clearly visible. Subsequent lists then had exposure durations reduced to 30, 20, 14, and then 10 ms. The exposure duration selected for each participant was the longest duration at which that participant accurately judged category membership at chance levels (< 60% of trials). Adjustments to prime exposure duration were made for some participants based on performance during the treatment task; these cases are described individually below.

**Treatment Session Protocol**

Participants were seen for two sessions per treatment day with a minimum 1-hour break in between. There were 12 treatment sessions for each semantic category. During treatment sessions, participants sat at a comfortable distance from the computer screen in a quiet room and watched stimuli presented on the screen. In each trial, the participant saw the masked prime (identity or sham) followed by the target picture a total of four times; they were instructed to only watch the screen for the first three presentations and then to try to name the picture on the fourth presentation, when the picture was presented with a green frame (see Figure 2 for details of the stimulus presentation sequence). Each item was repeated four times per session, for a total of 16 prime-target exposures and four naming opportunities. Participants had 10 s to respond for each picture naming attempt. There was a 1-s blank screen presented between each prime-target presentation within a trial and a 4-s blank screen between trials after each naming attempt. Participants were not told about the masked primes and were given no feedback at any time. Details of all participants' treatment parameters are presented in Table 3.

**Figure 1.** Stimulus presentation sequence for a single trial of the visibility assessment task. Reproduced from "Masked repetition priming in treatment of anomia: A Phase 2 study," by J. P. Silkes, 2015, *American Journal of Speech-Language Pathology, 24,* pp. S895–S912. Copyright © 2015 by American Speech-Language-Hearing Association. Reprinted with permission.




**Outcome Measures**

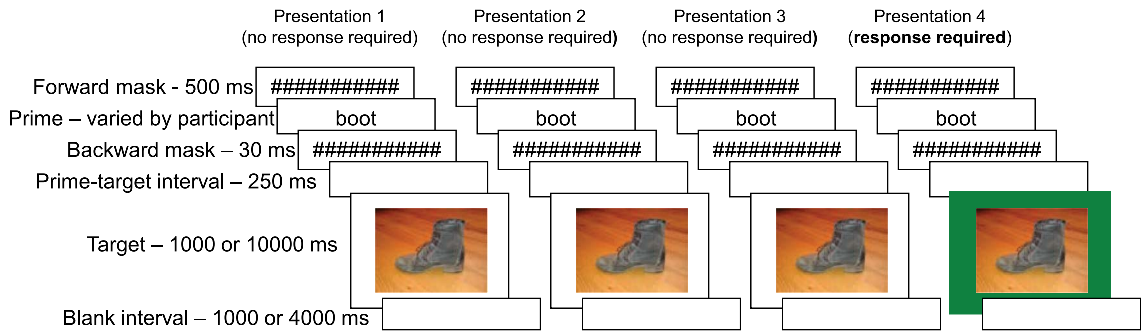
Naming probes containing all T and UE items were administered before every third treatment session. In addition, three posttreatment probes containing all T, UE, and UU items were conducted in the week immediately after treatment completion, and three maintenance probes containing those same items were conducted 3 months later. The primary outcome measure was accuracy on these probes.

Secondary outcome measures included (a) response latency measures for correct responses on the naming probes: This was undertaken to determine if retrieval became more efficient, based on observations during pilot testing that not only were more targets named accurately over the course of treatment but also many responses that were accurate early in the protocol were produced more quickly over time, suggesting that retrieval was becoming more efficient as well as more accurate; (b) two measures of broader language skills: The WAB (Kertesz, 1982) was used as an index of changes in overall language ability (a change of > 5 on the aphasia quotient is deemed clinically significant; Katz & Wertz, 1997), and the BNT (Kaplan et al., 2001) was used as an index of change in general naming skills; (c) discourse samples in response to the prompts "What happened to you to cause your aphasia?", "What effects does your aphasia have on your life?", and "Tell me about a typical day, from when you wake up in the morning until you go to bed at night.": These were used to assess changes in discourse level language through calculating percent correct information units (CIUs), which reflect the effectiveness and content relevance of verbal messages, and CIUs per minute, which reflect communicative efficiency (Nicholas & Brookshire, 1993); and (d) the Five Point Test (Regard, Strauss, & Knapp, 1982) as an index of changes in nonlinguistic cognitive function: This was a control measure, and no change was expected.

## *Data Processing and Analysis*

The primary outcome measure, response accuracy on naming probes, was initially recorded by the author during probe sessions and then was verified by trained listeners from audio recordings. A naming response was considered

**Figure 2.** Stimulus presentation sequence for a single training trial. Reproduced from "Masked repetition priming in treatment of anomia: A Phase 2 study," by J. P. Silkes, 2015, *American Journal of Speech-Language Pathology, 24,* pp. S895–S912. Copyright © 2015 by American Speech-Language-Hearing Association. Reprinted with permission.




accurate if the target name was produced at any time during the 10 s that the target picture was visible on the screen. Words that were distorted were counted as correct if the distortion did not create a different phoneme. Words that were variants of the target were counted as correct if they were inflectional changes (e.g., "sandals" for *sandal*) but not if they were derivational changes (e.g., "hike" for *hiking*).

Effect sizes were calculated for naming probe accuracy data using Busk and Serlin's (1992) formula: $d = (\text{Mean}_{\text{posttreatment}} - \text{Mean}_{\text{baseline}})/SD_{\text{baseline}}$. Acquisition effects for each participant's L1 were calculated using the eight naming probes administered after treatment of L1 concluded compared with the seven initial baseline probes. For each participant's second semantic category trained (L2), acquisition effects were calculated using the three naming probes administered in the week after completion of L2 treatment, compared with both the initial and extended (during treatment of L1) baseline probes combined. Maintenance effects were calculated for both L1 and L2 using the three probes administered 3 months after treatment as compared with the first seven baseline probes. Cross-category generalization effects were calculated based on the six extended baseline naming probes for T and UE items in L2 as compared with the seven initial baseline probes for those items. Effect sizes of > 2.6 were considered to be small, > 3.9 were medium, and > 5.8 were large (Beeson & Robey, 2006).

For the secondary measure of response latency for correct responses on naming probes, latency measures were made manually, from the onset of picture presentation, marked by an audio tone, to the onset of the first production of a correct response. For two-word targets (e.g., proper names), measurements were made to the onset of the second word. Response latencies were analyzed with regression analysis to identify any significant patterns of change over the course of the treatment program, as seen by the ability to predict response latency based on the probe session (i.e., how early or late in the program the probe occurred).

To calculate CIU measures, language samples were transcribed by a research assistant and these transcripts were checked and verified by the author. Percent CIUs and CIUs per minute were calculated according to the guidelines described by Nicholas and Brookshire (1993).

Changes on the Five Point Test were assessed using *t* tests with equal variance assumed, comparing scores immediately posttreatment and at maintenance with pretreatment scores.

**Table 3.** Treatment delivery parameters.

| ID | Semantic categories treated | Treatment schedule | Prime exposure duration |
|---|---|---|---|
| PN | L1: Sports and games | 4×/week | 14 |
| | L2: Famous people | | 20 |
| PP | L1: Famous people - other | 5×/week | 20 |
| | L2: Famous people - entertainment | | 14 |
| PR | L1: Things to wear | 5×/week | 30 → 40 |
| | L2: Tools | | 60 |
| PS | L1: Things to wear | 5×/week | 50 |
| | L2: Produce | | 20 |
| PU | L1: Famous people - entertainment | 4×/week | 14 |
| | L2: Famous people - other | | 14 |
| PV | L1: Famous people - other | 4×/week | 10 |
| | L2: Famous people - entertainment | | 14 |

*Note.* L1 = first semantic category list; L2 = second semantic category list; PN = Participant N; PP = Participant P; PR = Participant R; PS = Participant S; PU = Participant U; PV = Participant V.

Although not an outcome measure, response accuracy during treatment sessions was also recorded and analyzed to determine whether the presence of masked primes made an immediate difference in naming accuracy, regardless of the outcome of naming probe measures. For this measure, the experimenter recorded naming accuracy within 10 s for each of the four naming opportunities for each T and UE item in each training session. Between-condition differences were calculated using *t* tests assuming equal variance.

### *Reliability*

The author scored all responses for accuracy initially, and a research assistant scored 25% of the responses for each participant to calculate interrater reliability. Overall interrater reliability was 97.5%. Timing measures were made by the author or a research assistant, and 20% of them were measured again by a second research assistant. Interrater agreement on timing measures, defined as the response latency measures being within 100 ms of each other, was 91.67%. CIU measures were calculated on full language samples separately by the author and a research assistant, who then reviewed their scoring in full and came to consensus on any points of divergence.

## Results

All data were analyzed using single-subject design methodology and are reported independently for each participant. To avoid significant redundancy across the individual participant results sections, all outcome data are included in Tables 4 and 5.

### *Protocol Details and Results: Participant N*

Participant N (PN) presented with fluent and grammatic connected speech, characterized by frequent hesitations and circumlocutions. She typically recognized production errors. On the basis of initial threshold testing, her prime exposure duration was initially set at 30 ms. During her second L1 training session, however, she became aware of the primes, demonstrated by sudden high levels of success with naming; in addition, she commented afterward that "some of them have real words in there and some of them have garbage." Because of this increased awareness, her prime exposure duration was reduced to 14 ms for all subsequent L1 sessions. When she showed high levels of frustration during L1, during which time she showed no change in naming ability (see details below), she was offered the choice of continuing with the same protocol parameters, discontinuing the program, or continuing the program with some changes to the parameters (although she was not told the details of what those parameters were). She chose to continue with changed parameters, so L2 was trained with a prime exposure duration of 20 ms. At no time during or after training of L2 did she express awareness of the prime items. In addition, her gradual improvement in naming during treatment sessions (see details below) suggests that she was not consciously reading the identity primes, as conscious reading would have immediately led to consistently accurate naming during treatment sessions, as was seen for L1.

#### Stimuli

Treatment was conducted for the categories of "sports and games" (L1) and "famous people" (L2; see Appendix A). There were nine items in each condition for L1 and 10 items in each condition for L2.

#### Results

See Tables 4 and 5 and Figures 3 and 4 for a summary of PN's outcomes. Her response latencies for correct items on naming probes did not change over the course of treatment, $F(1, 11) = 0.619$, $p = .448$, with an $R^2 = .05$.

#### Discussion

Overall, PN did not ultimately benefit from this treatment protocol in terms of accuracy on naming probes, although changes were noted on CIU measures from pretreatment to maintenance testing. For the T items, she

**Table 4.** Summary of effect sizes (*d*) for all participants.

| | PN | | PP | | PR | | PS | | PU | | PV | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Condition** | **L1** | **L2** | **L1** | **L2** | **L1** | **L2** | **L1** | **L2** | **L1** | **L2** | **L1** | **L2** |
| Immediately posttreatment | | | | | | | | | | | | |
| Trained | –0.54 | 1.97 | 18.07[a] | 9.77[a] | 0 | 0 | 8.65[a] | 3.66[b] | 9.19[a] | 6.60[a] | 5.91[a] | 5.85[a] |
| UE | 0.32 | –0.39 | 6.72[a] | 6.93[a] | 0 | 0 | 7.34[a] | 4.65[c] | 4.48[c] | 5.06[c] | 12.85[a] | 8.47[a] |
| UU | 0.41 | 0.45 | 0.94 | 3.61[b] | 0 | 0 | 4.78[c] | 3.15[b] | 0.63 | 2.83[b] | 4.91[c] | 0 |
| Cross-category generalization | | –0.58 | | 2.36 | | 0 | | 1.04 | | 4.74[c] | | 1.89 |
| Maintenance | | | | | | | | | | | | |
| Trained | –0.95 | 1.22 | 5.24[c] | 2.83[b] | 0 | 0 | 7.43[a] | 1.66 | 7.01[a] | 5.66[c] | 2.27 | 1.12 |
| UE | –0.08 | 0 | 0.94 | 0 | 0 | 0 | 6.48[a] | 5.43[c] | 4.09[c] | 7.54[a] | 6.68[a] | 4.03[c] |
| UU | 0.21 | –0.61 | 1.89 | 0.94 | 0 | 0 | 4.78[c] | 1.83 | 1.57 | 0.94 | 0.50 | 0.71 |

*Note.* L1 = first semantic category list; L2 = second semantic category list; PN = Participant N; PP = Participant P; PR = Participant R; PS = Participant S; PU = Participant U; PV = Participant V; UE = untrained–exposed; UU = untrained–unexposed.

[a]A large effect. [b]A small effect. [c]A medium effect.

**Table 5.** Summary of scores for all participants' language generalization measures.

| Participant | Measure | Pretreatment | Immediately posttreatment | Maintenance |
|---|---|---|---|---|
| PN | WAB | 90.8 | 90.8 | 88.8 |
| | BNT | 42 | 44 | 32 |
| | % CIUs | 78.18 | 75.42 | 84.00 |
| | CIUs/min | 68.79 | 52.85 | 82.13 |
| PP | WAB | 81.6 | 82.8 | 83.6 |
| | BNT | 46 | 45 | 48 |
| | % CIUs | 73.43 | — | 80.15 |
| | CIUs/min | 141.22 | — | 124.37 |
| PR | WAB | 28.4 | 39.3 | 37.6 |
| | BNT | 2 | 2 | 2 |
| | % CIUs | 67.19 | 64.67 | 67.24 |
| | CIUs/min | 93.73 | 85.29 | 96.73 |
| PS | WAB | 54.0 | 64.5 | 62.9 |
| | BNT | 19 | 23 | 20 |
| | % CIUs | 67.05 | 68.90 | 70.80 |
| | CIUs/min | 74.60 | 99.20 | 111.67 |
| PU | WAB | 77.2 | 75.6 | 74.0 |
| | BNT | 31 | 40 | 35 |
| | % CIUs | 68.23 | 67.84 | 69.48 |
| | CIUs/min | 85.13 | 95.39 | 105.02 |
| PV | WAB | 88.4 | 91.4 | 90.4 |
| | BNT | 43 | 40 | 46 |
| | % CIUs | 81.78 | 80.71 | 84.09 |
| | CIUs/min | 114.77 | 108.09 | 112.77 |

*Note.* BNT = Boston Naming Test; CIUs = correct information units; PN = Participant N; PP = Participant P; PR = Participant R; PS = Participant S; PU = Participant U; PV = Participant V; WAB = Western Aphasia Battery.

**Figure 3.** Naming accuracy during training sessions for Participant N for L1 (a) and L2 (b). The peak for trained items in L1 training session 2 reflects the participant's recognition of the masked primes; see text for details. L1 = first semantic category list; L2 = second semantic category list.

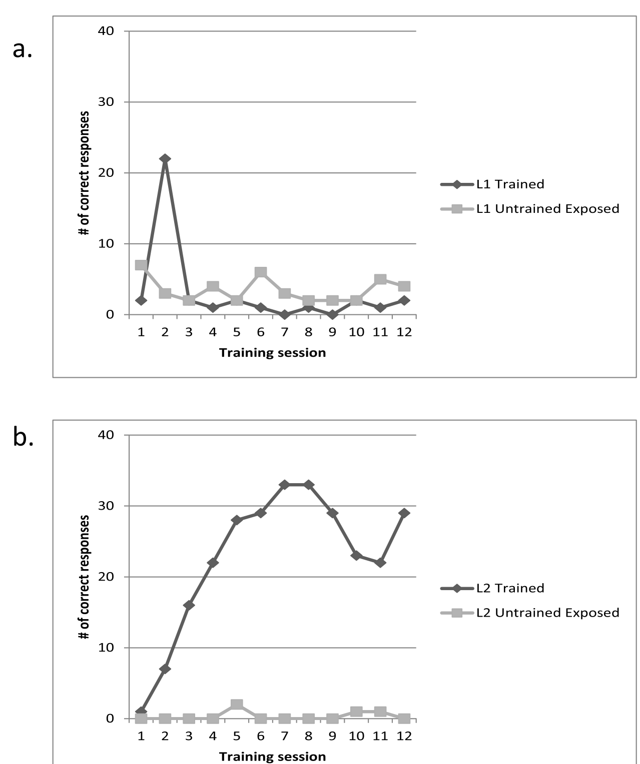
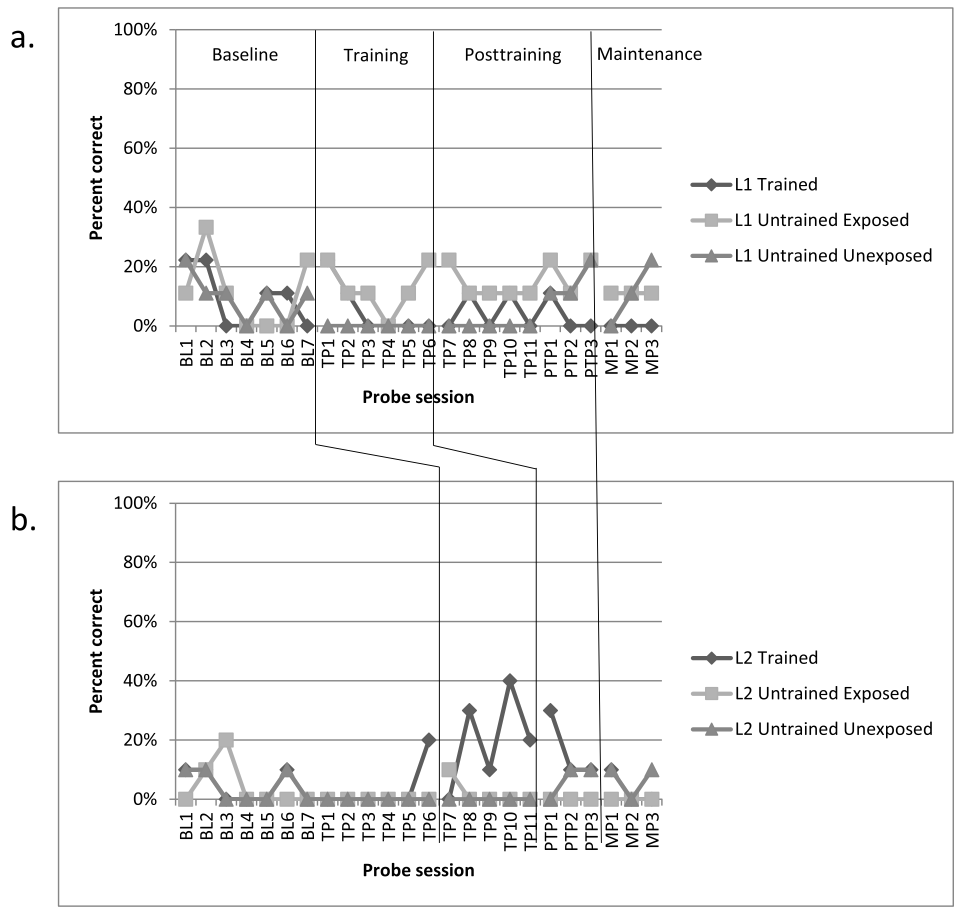


**Figure 4.** Accuracy on naming probes for Participant N for L1 (a) and L2 (b). L1 = first semantic category list; L2 = second semantic category list.




benefited from the presence of prime words during treatment sessions when the prime words were presented for 20 ms (during L2), as shown by her greater accuracy in naming primed items than unprimed items. During naming probes, however, when there were no primes presented, she did not carry over learning from the treatment sessions to improved naming on the probes. She showed no significant change in naming latencies over the course of treatment.

There are a few considerations regarding this participant that may help to explain her poor outcome. PN met all inclusion criteria for this study and had fairly good communication abilities but, in retrospect, presented with evidence of impaired cognitive function that was not captured by this protocol's screening procedures. This included poor retention of information from day to day when it was clear that she had understood it when it was first presented and impaired reasoning in daily functional situations. Since the study has been completed, PN has been found to have generalized neurological changes consistent with alcoholism and/or traumatic brain injury with no specific known date of injury. It is possible that whatever mechanisms have led to those later changes were influencing her performance in this study before they were identified.

This participant's poor response to treatment suggests that, although this treatment approach is designed to tap implicit mechanisms, conscious reflection and self-correction of productions may play a significant role in a person's reestablishment of lexical network connections as they attempt to produce the same targets repeatedly across trials and sessions. This would be consistent with prior work that demonstrates a role of attention in implicit processing (e.g., Musen & Viola, 2000). Future investigations should therefore consider each participant's broader cognitive skills more thoroughly to determine what abilities are needed intact to make this treatment an appropriate choice.

### *Protocol Details and Results: Participant P*

Participant P (PP) presented with fluent and grammatic connected speech, characterized by frequent hesitations, circumlocutions, and use of nonspecific vocabulary. On the basis of initial threshold testing, his prime exposure duration was set at 30 ms, but similar to PN, he showed overt signs of consciously processing the masked items in the first treatment session. Therefore, his exposure duration was reduced to 20 ms for the remainder of L1 training sessions. At this exposure duration, he did not immediately respond correctly to all of the primed items, indicating that the masking was somewhat effective, but he continued to make comments that demonstrated that he was not only aware of the presence of the primes but also was using a conscious approach to them (e.g., "Has an 'x' in there" and "It's like some of them the name's not really in there."). Given that previous work has demonstrated that masked items that are even slightly above the threshold of visibility may induce explicit processing mechanisms that can overshadow implicit mechanisms (Dagenbach, Carr, & Wilhelmsen, 1989), his prime exposure duration was reduced further for L2. Once the exposure duration was reduced, he seemed to continue using an explicit approach, as he was aware that the primes were present and might prove useful, but made fewer comments indicating that he was actively seeing the masked primes.

### Stimuli

Treatment was conducted for "famous people: other" (L1) and "famous people: entertainment" (L2). There were 10 items in each condition for both categories (see Appendix B).

### Data Analysis

Because all L1 baseline naming probes were 0% accurate, a standard deviation could not be derived from the baseline probes to include in the effect size calculation. Therefore, a standard deviation was derived from the UE baseline probes plus the first training probe, as these items had additional exposure without any item-specific training. This standard deviation was then applied to effect size calculations for all conditions in L1. This problem did not arise for T and UE items in L2 because extended baselines had scores > 0. The *SD* from L2 UE items was used for the effect size calculation for L2 UU items, which had only the original seven pretreatment baseline probes. Discourse data were not available immediately posttreatment because of problems with the audio recording equipment. PP's maintenance data were collected 4 months after completing treatment because of scheduling issues.

### Results

See Tables 4 and 5 and Figures 5 and 6 for a summary of PP's outcomes. His response latencies for correct items on

**Figure 5.** Naming accuracy during training sessions for Participant P for L1 (a) and L2 (b). L1 = first semantic category list; L2 = second semantic category list.

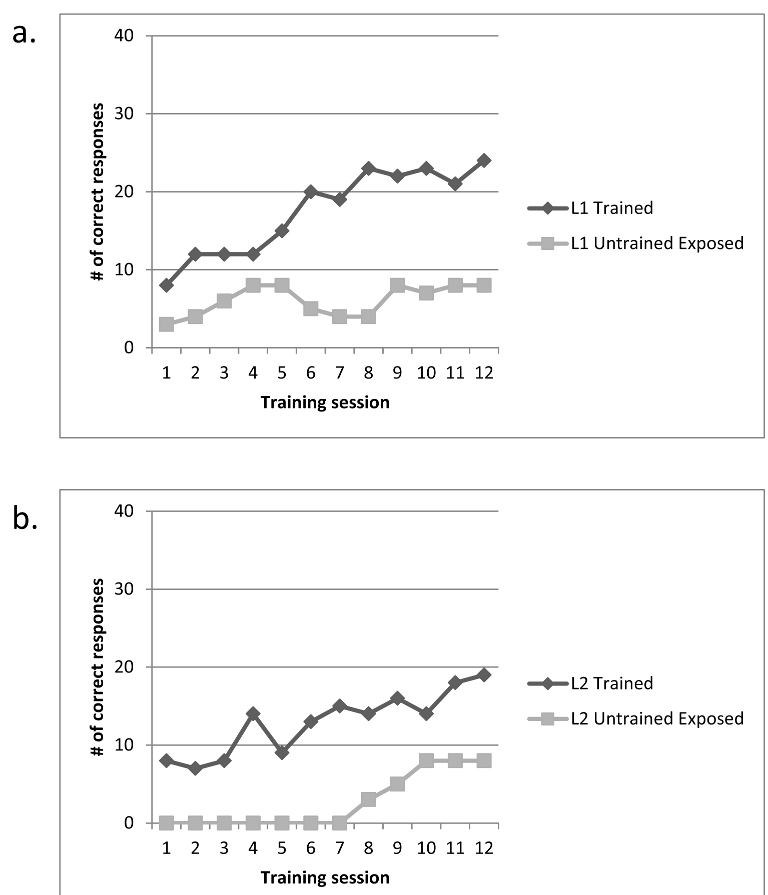
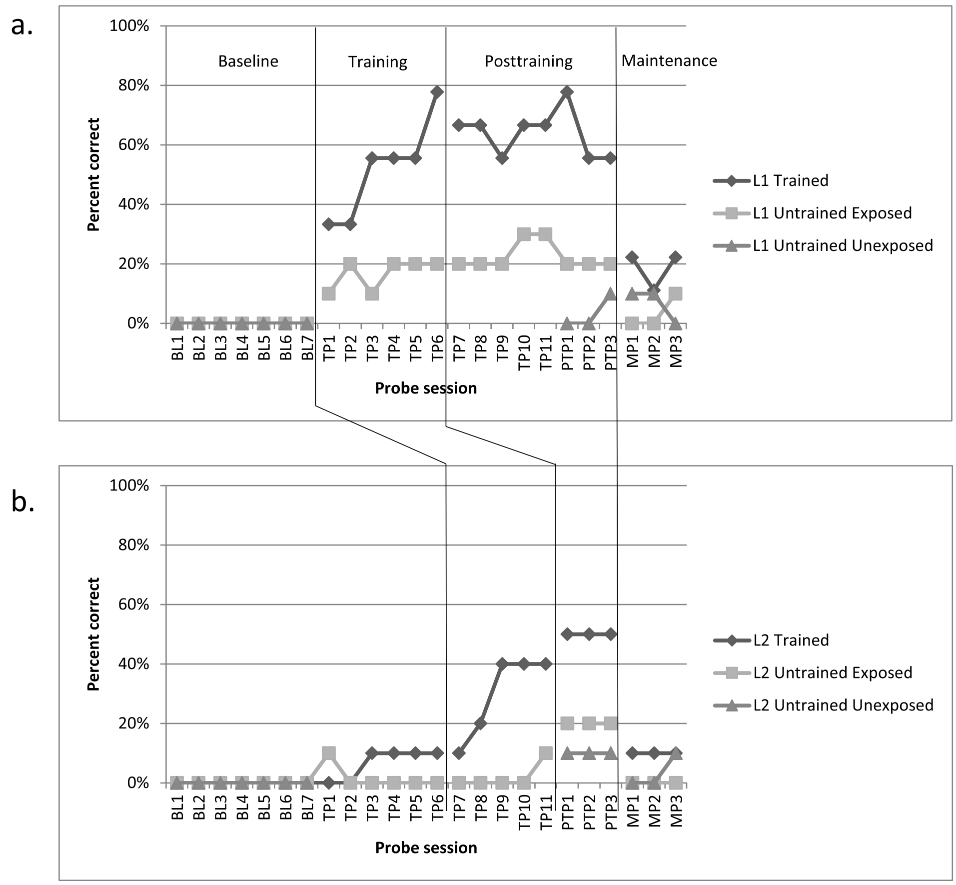


**Figure 6.** Accuracy on naming probes for Participant P for L1 (a) and L2 (b). L1 = first semantic category list; L2 = second semantic category list.




naming probes did not change over the course of treatment, $F(1, 14) = 3.16$, $p = .097$, with an $R^2 = .18$.

**Discussion**

PP showed improvement in naming of all three types of stimuli (T, UE, and UU) for both stimulus sets, with the largest effects for the T items, followed by the UE items. He had no significant change in response latencies for naming. This outcome suggests that repeated exposure to UE items provided some benefit but that providing the masked prime words augmented that benefit. Within-category generalization to UU items suggests that the training protocol may have strengthened related lexical networks, although generalization effects for this participant did not extend across semantic categories, contrary to previous findings with this protocol (Silkes, 2015; Silkes et al., 2013). His improved percent CIUs suggest greater accuracy of language production in functional contexts, although his discourse efficiency did not improve.

## *Protocol Details and Results: Participant R*

Participant R (PR) presented with fluent and grammatic connected speech, but with a predominance of nonspecific language and frequent semantic paraphasias. Auditory comprehension was poor. Single-word reading comprehension was largely intact, but he was unable to read words aloud and single-word repetition was poor. Visibility testing was conducted using two different methods. The first, as has been described for the previous participants, involved making category decision judgments on masked and visible items. Because the previous participants' patterns of performance had raised the question of whether this method was adequate, especially for long exposure durations, a second task was developed for PR to verify whether the selected prime exposure duration was effective at masking the prime words. This involved presenting masked words before pictures and having the participant make decisions about whether the prime word and picture matched. On the basis of this initial threshold testing and verification, his prime exposure duration was set to 30 ms, but this was increased to 40 ms after a few L1 training sessions because of his extreme frustration. As described for PN, when PR showed high levels of frustration during L1, during which time he showed no change in naming ability (see details below), he was offered the choice of continuing with the same protocol parameters, discontinuing the program, or continuing the program with some changes to the parameters (although he was not told the details of what those parameters were). He chose to continue with changed parameters, so L2 was trained with a prime exposure duration of 60 ms.

### Stimuli

Treatment was conducted for "things to wear" (L1) and "tools" (L2). There were 10 items in each condition for both categories (see Appendix C).

### Results

See Tables 4 and 5 and Figures 7 and 8 for a summary of PR's outcomes. Response latency measurement could not be completed because no correct responses occurred.

### Discussion

PR was the second participant who did not respond to this treatment, although he presented with a very different cognitive–linguistic profile from the first participant (PN). His general cognitive status was unimpaired, with good retention of information between sessions and days and excellent daily problem-solving skills. His language skills, however, were unique among all of the participants in this study. He had almost no ability to read words aloud or repeat words, despite demonstrating comprehension of those single words. This pattern of performance suggests a particularly impaired link between the linguistic domains of phonology, semantics, and orthography, with weakness specifically in phonological representations. As a result, despite prior evidence that some people who are not able to read words aloud can nonetheless process those words at some level (e.g., Revonsuo, 1995; Roberts et al., 2010), PR's nonresponse to this treatment suggests that this ability to glean semantic information from words that cannot be read aloud may not be adequate for stimulating related networks to overcome severely impaired links between orthography and phonology or severely impaired phonological processing. Therefore, this treatment approach is likely not appropriate for people who are not able to read single words aloud, even if they demonstrate comprehension of those words, although it would be worthwhile to replicate this finding in additional individuals with aphasia.

Interestingly, although PR did not show improvements on naming probes, he did show improvements on general

**Figure 7.** Naming accuracy during training sessions for Participant R for L1 (a) and L2 (b). L1 = first semantic category list; L2 = second semantic category list.

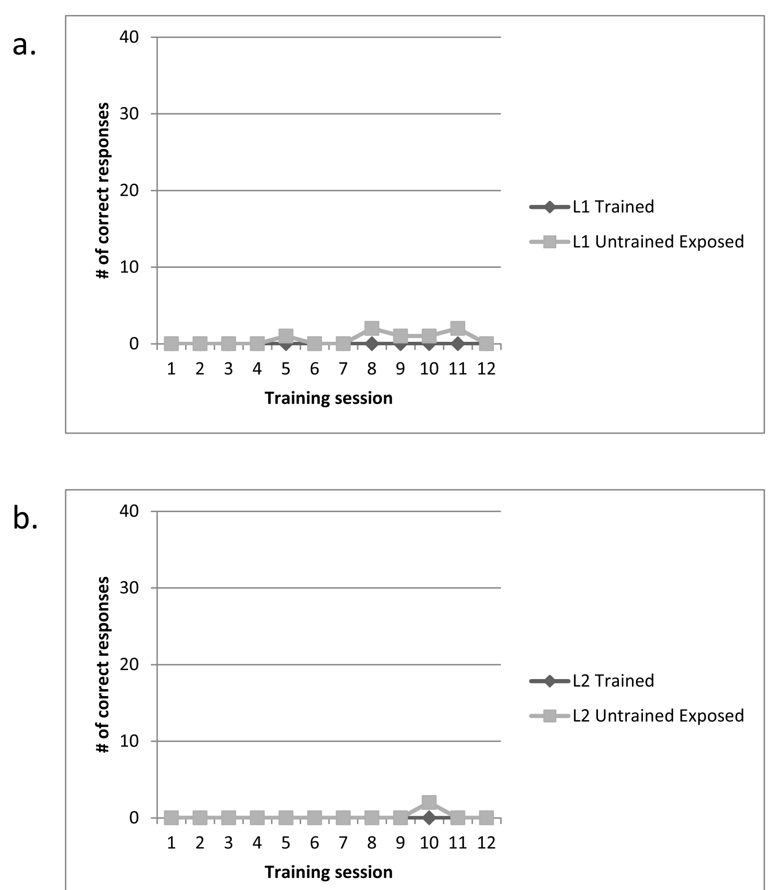
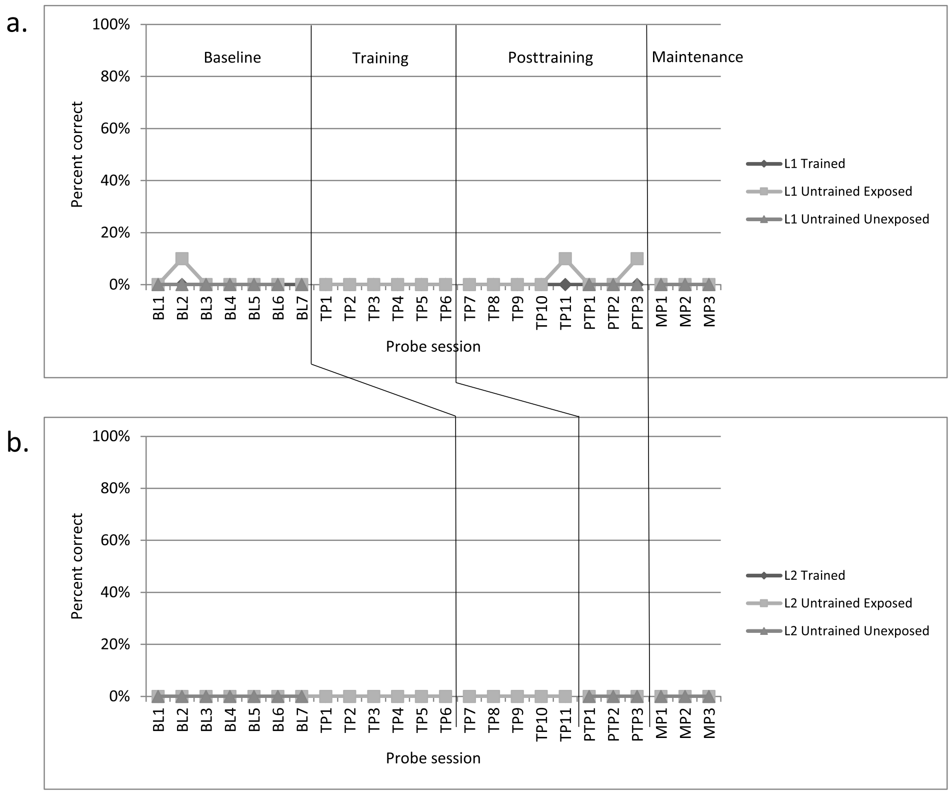


**Figure 8.** Accuracy on naming probes for Participant R for L1 (a) and L2 (b). L1 = first semantic category list; L2 = second semantic category list.




language processing abilities, across expressive and receptive tasks, as demonstrated by improvements in his WAB–Aphasia Quotient. It is difficult to know specifically, what led to this improvement. It is possible that he improved in overall attentional abilities as related to language, given the extensive need for sustained attention in the treatment task, and that this resulted in his being better able to process the language material on the WAB or that his greater level of comfort with the examiner resulted in his improved performance.

## *Protocol Details and Results: Participant S*

Participant S (PS) presented with fluent and grammatic connected speech, characterized by frequent hesitations, circumlocutions, and use of nonspecific vocabulary, with frequent semantic paraphasias. He had no dysarthria or apraxia of speech. Visibility testing was conducted using the two different methods described for PR. On the basis of these results, an exposure duration of 50 ms was selected for L1. There was no indication that he was seeing any of the primes until the 11th training session, when he suddenly exclaimed, "I saw the word there! There are words in there!"; performance from that point on was excellent for T items.

Because of this newfound ability to see the primes, visibility was retested before beginning L2. On the basis of these results, L2 was trained with 20-ms primes. When he began with L2, he indicated that he could no longer see the prime words and was confused by that. He gave no indication at any time during L2 training that he could see the items.

### Stimuli

Treatment was conducted for "things to wear" (L1) and "produce" (L2). There were 10 items in each condition for L1 and eight per condition for L2 (see Appendix D).

### Data Analysis

Standard deviations were derived in the same manner described above for PP, for the same reasons.

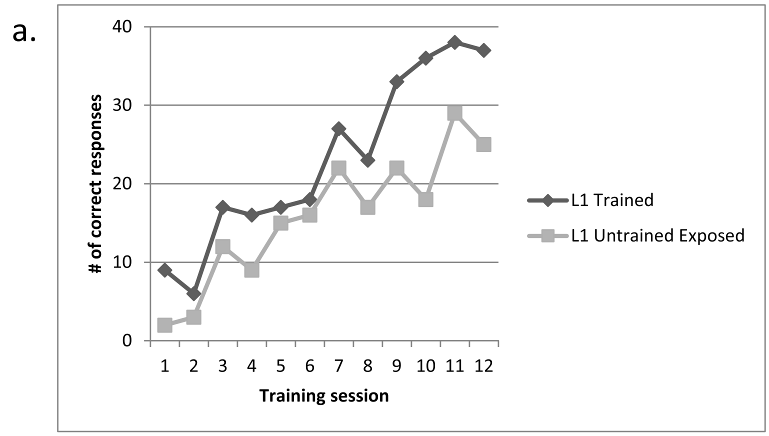
### Results

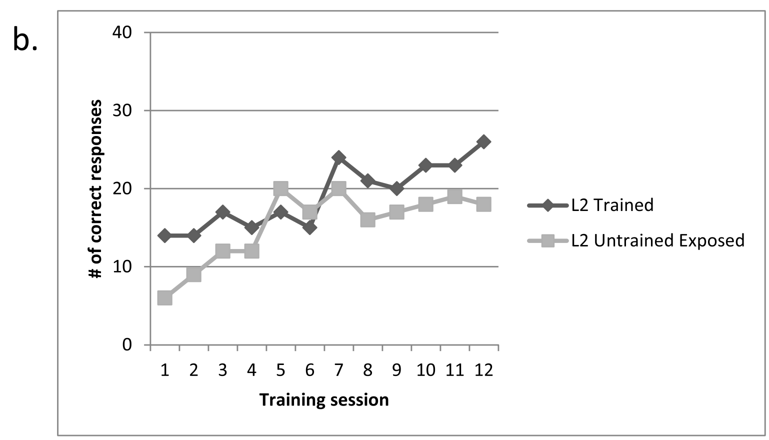
See Tables 4 and 5 and Figures 9 and 10 for a summary of PS's outcomes. Response latencies for correct items on the naming probes got significantly faster over the course of the treatment program, $F(1, 22) = 16.61$, $p \leq .001$, with an $R^2 = .43$.

### Discussion

PS showed improvement in naming of all three categories of stimuli (T, UE, and UU) for both stimulus sets,

**Figure 9.** Naming accuracy during training sessions for Participant S for L1 (a) and L2 (b). L1 = first semantic category list; L2 = second semantic category list.




with improvements maintained over time. Larger effect sizes were seen for acquisition of T than UE items in L1, indicating that repeated exposure to UE items provided some benefit but that providing the masked prime words augmented that benefit; this pattern was reversed for L2, with UE items showing a slightly larger effect size than T items. For both training lists, effect sizes for UU items were the smallest. There was no cross-category generalization, contrary to previous findings with this protocol (Silkes, 2015; Silkes et al., 2013). PS is the one participant reported here for whom response latencies for naming items correctly improved significantly over the course of the training program, possibly reflecting improved efficiency of word retrieval processes. Although his formal language test scores (WAB and BNT) did not show notable improvements, he showed changes in discourse measures. These included a small improvement in percent CIUs, reflecting somewhat better accuracy of content, and a large improvement in CIUs per minute, reflecting better communicative efficiency. For both outcome measures, improvements were greater at maintenance than they had been immediately after treatment.

## *Protocol Details and Results: Participant U*

Participant U (PU) presented with fluent and grammatic connected speech, characterized by use of nonspecific vocabulary, with frequent phonologic paraphasias. An exposure duration of 14 ms was selected based on her performance on the primary visibility task.

### Stimuli

Treatment was conducted for “famous people: entertainment” (L1) and “famous people: other” (L2). There were 10 items in each condition for each semantic category (see Appendix E).

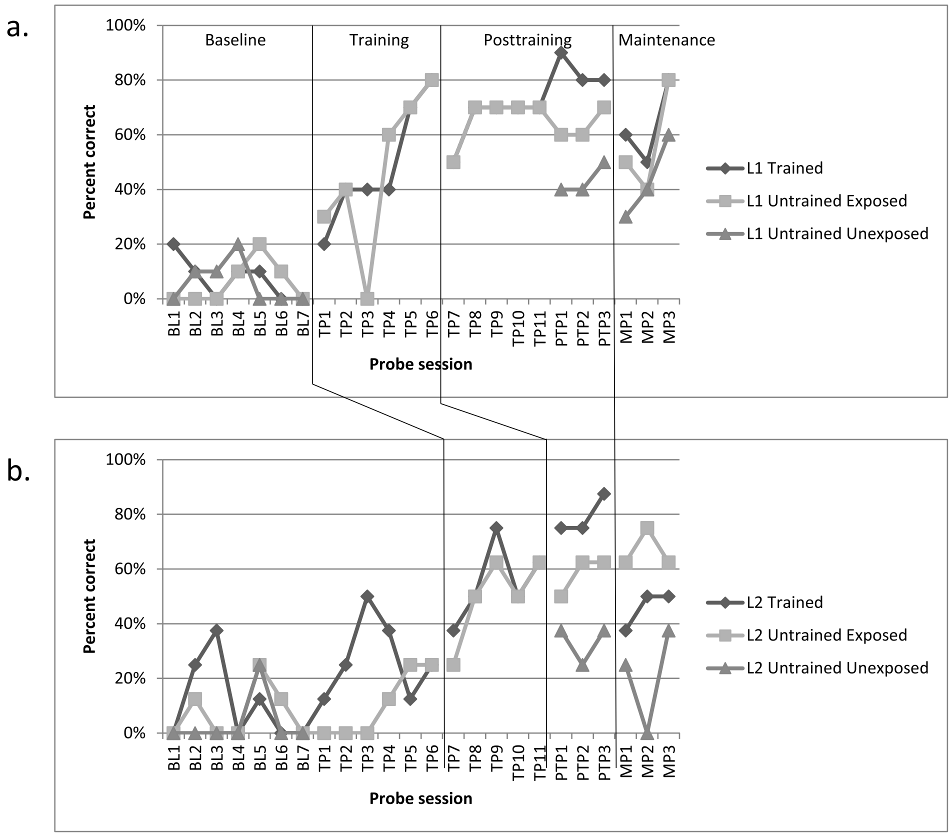
### Data Analysis

Standard deviations were derived in the same manner described above for PP, for the same reasons.

### Results

See Tables 4 and 5 and Figures 11 and 12 for a summary of PU’s outcomes. Response latencies for correct

**Figure 10.** Accuracy on naming probes for Participant S for L1 (a) and L2 (b). L1 = first semantic category list; L2 = second semantic category list.




items did not change significantly over the course of treatment, $F(1, 15) \leq 0.001$, $p = .99$, with an $R^2 \leq .001$.

### Discussion

PU showed improvement in naming of both T and UE items in L1 and of items in all three stimulus conditions (T, UE, and UU) in L2, with improvements maintained over time for T and UE items in both lists. Larger effect sizes were seen for acquisition of T than UE items in both lists, again indicating that repeated exposure to UE items provided some benefit but that providing the masked prime words augmented that benefit. Maintenance was greater for T than UE items in L1, but this pattern was reversed for L2, with UE items showing a slightly larger effect size at maintenance than T items. Consistent with previous work (Silkes, 2015; Silkes et al., 2013), cross-category generalization was seen, with improved naming of L2 items during training of L1. Whereas response latencies for naming probe items correctly, formal language test scores (WAB and BNT), and accuracy of discourse content did not show notable improvements, she showed a large improvement in CIUs per minute, reflecting better communicative efficiency; as seen for PS, this improvement continued to grow between posttreatment and maintenance testing.

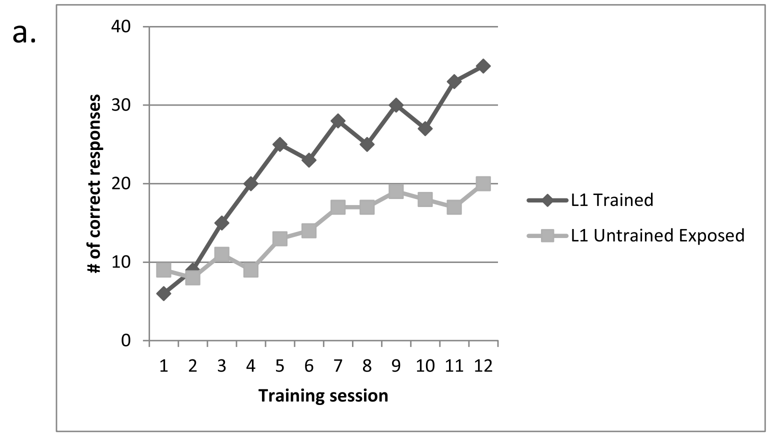
## *Protocol Details and Results: Participant V*

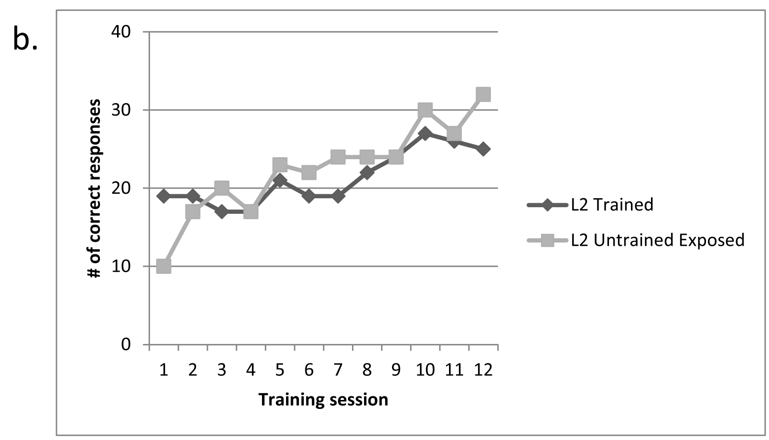
Participant V (PV) presented with fluent and grammatic connected speech, characterized by frequent hesitation and use of nonspecific vocabulary. He had no dysarthria but presented with a mild apraxia of speech characterized by occasional sound distortions. The same two-step approach to visibility testing described for PS was implemented with PV. He scored 2 of 10 accurate correct category identification of masked food names at the 14-ms exposure duration on the primary visibility task and 0 of 10 at 10-ms exposure duration; both were within the definition of "chance" performance, but it was unclear which would be the better option to maximize priming effects while minimizing conscious awareness of the prime items. On the second task, PV scored 11 of 20 accurate ($d' = 0.15$) determining if prime words and pictures matched at the 14-ms exposure duration and 10 of 20 ($d' = 0$) at the 10-ms exposure duration. On the basis of this information, a 10-ms prime exposure duration was selected for L1, but this was changed to 14 ms for L2 for reasons discussed below.

### Stimuli

Treatment was conducted for "famous people: other" (L1) and "famous people: entertainment" (L2). There were

**Figure 11.** Naming accuracy during training sessions for Participant U for L1 (a) and L2 (b). L1 = first semantic category list; L2 = second semantic category list.




eight items in each condition for L1 and 10 items in each condition for L2 (see Appendix F).

### Data Analysis

Because PV scored 0% on UE and UU items for L2 baselines as well as the first training probe, the standard deviation from L2 T items' extension into the first training probe was applied to effect size calculations for L2 UE and UU items.

### Results

See Tables 4 and 5 and Figures 13 and 14 for a summary of PV's outcomes. Response latencies for correctly named items on naming probes did not change significantly over the course of treatment, $F(1, 13) = 3.28$, $p = .09$, with an $R^2 = .449$.

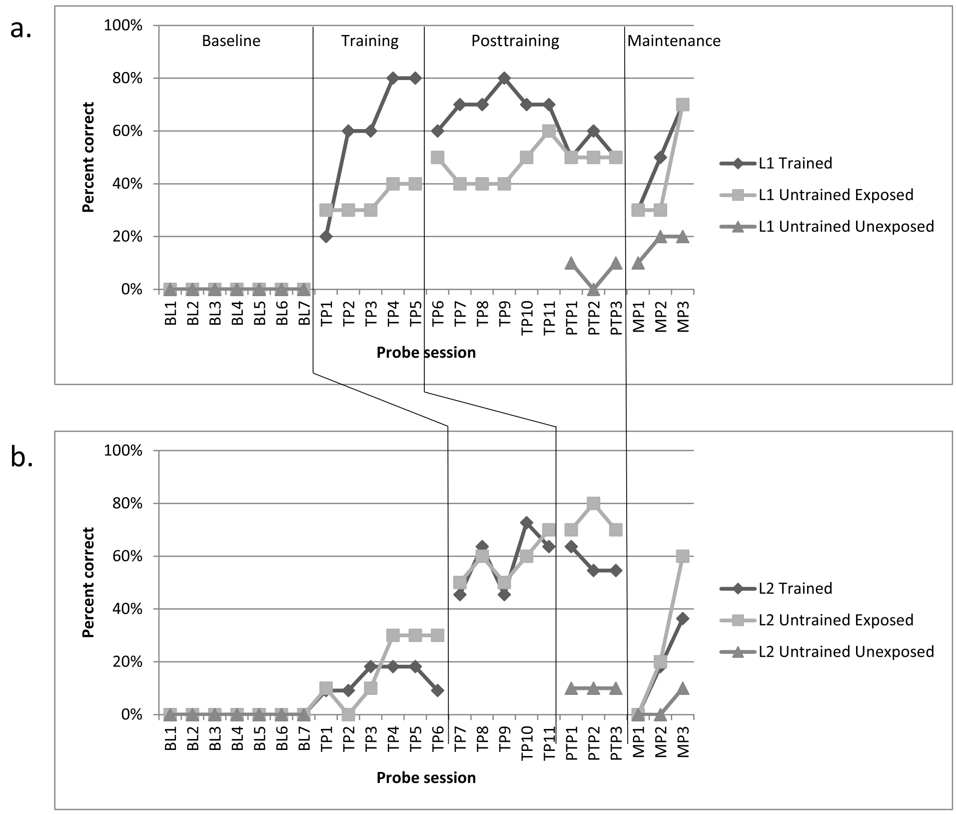
### Discussion

PV showed improvement in naming of all three stimulus categories (T, UE, and UU) for L1 and for T and UE items in L2. In both lists, surprisingly, improvements were larger for UE than T items, and improvements were maintained only for UE items in both lists. Although a 10-ms prime exposure duration was used for L1 because performance on pretesting was closer to completely chance performance, this paradoxical observation during training of L1 raised the question of whether better performance with UE than T items was due to the prime exposure duration in L1 being too short to be maximally useful. This led to raising the prime exposure duration for L2. This increase brought performance on the two treatment conditions closer to each other but did not lead to demonstrably greater effectiveness of the masked primes over simple repeated exposure to the training items. No cross-category generalization was seen, contrary to prior findings (Silkes, 2015; Silkes et al., 2013). No significant changes were seen in the measures of broader language function or efficiency of word retrieval.

## General Discussion

The data presented here provide continued support for a positive effect of masked primes on improvement in picture naming for some people with aphasia. Four of the six participants presented here showed significant

**Figure 12.** Accuracy on naming probes for Participant U for L1 (a) and L2 (b). L1 = first semantic category list; L2 = second semantic category list.



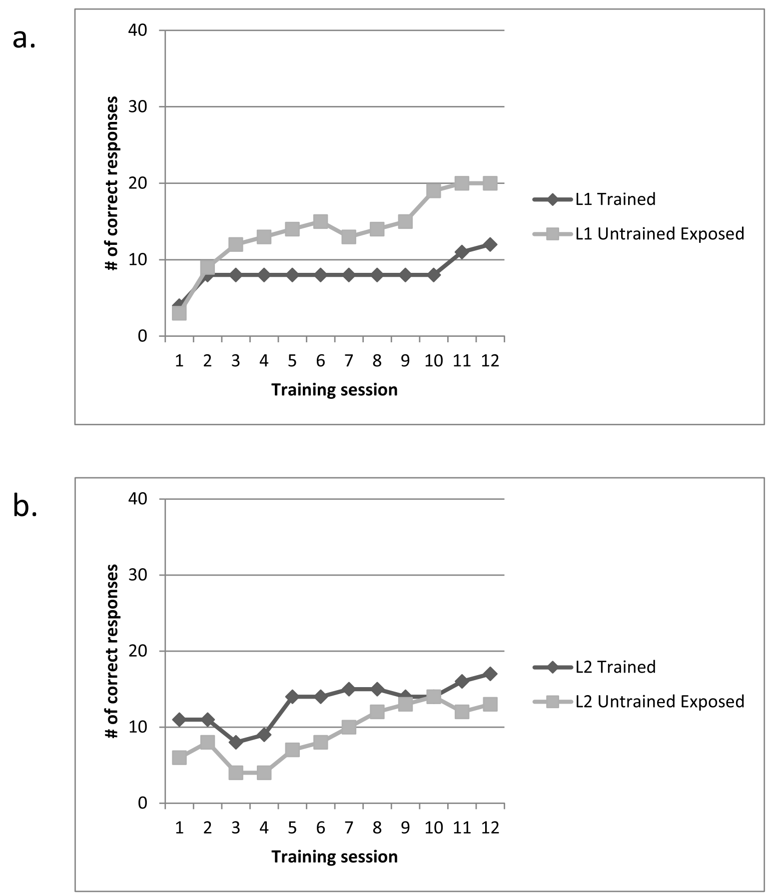

improvements in naming of T and UE items, with all but one of them showing an advantage for T items over UE items in at least one semantic category. Response latencies for correctly named items did not change significantly for most participants, suggesting that this may not have been a sensitive measure of retrieval efficiency in the context of this protocol. All but one participant (PV) improved in at least one measure of broader language function.

The general advantage for T over UE items indicates that the masked primes usually had an effect on naming that was beyond the effect of repeated exposure alone. This outcome is predicted by network models of lexical retrieval (Dell, 1986; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Nadeau, 2001), in which retrieval is the product of adequate (co)activation of component elements. Within the framework of these models, repeated exposure may encourage strengthening of existing connections in the language networks, but the presence of a masked prime facilitates this even further by preactivating lexical representations and repeatedly pairing them with semantic information, thereby making the words more available when naming is attempted. The few instances in which UE items showed greater improvement than T items suggest that the effectiveness of masked primes may interact with semantic or lexical parameters, such as semantic category, familiarity, or personal relevance, or may speak to the need to establish more sensitive criteria for determining the most appropriate prime exposure duration to ensure maximal effect and avoid any potential interference.

The presence of some generalization beyond trained and repeatedly exposed items is encouraging; all participants who responded to the treatment also showed some within-category generalization, with significant improvements in naming of UU items in at least one semantic category. Surprisingly, only one of the six participants showed cross-category generalization, which had been more evident in previous reports of treatment using masked repetition priming (Silkes, 2015; Silkes et al., 2013). These outcomes suggest that addressing lexical retrieval for some items may provide an opportunity for strengthening related networks, although the source of variability in generalization between participants and between semantic categories within the same participant warrants further exploration.

Although results for acquisition of the T items are positive, 3-month maintenance data are more difficult to interpret. One might expect that T items would be maintained better than untrained items, but this was not the case for all participants. Of the four who responded to this treatment, two (PP and PU) maintained naming improvements relative

Figure 13. Naming accuracy during training sessions for Participant V for L1 (a) and L2 (b). L1 = first semantic category list; L2 = second semantic category list.




to baseline for T items in both semantic categories 3 months after treatment ended. One of these participants (PP) showed no maintenance of UE items, whereas the other (PU) maintained gains for UE items in both semantic categories and even improved naming in one category. In contrast, one of the remaining participants (PS) maintained gains for T items in only one semantic category, and the other (PV) did not maintain gains for T items at all; both of these participants maintained gains for UE items in both semantic categories, and one (PS) retained UU generalization gains as well. There is no obvious pattern in these results, suggesting that there are a variety of factors that influence the response to this treatment approach and retention afterward. These factors may include the semantic categories trained, the exposure duration of the masked primes, or participant factors that influence the ability to reflect on and integrate learned material.

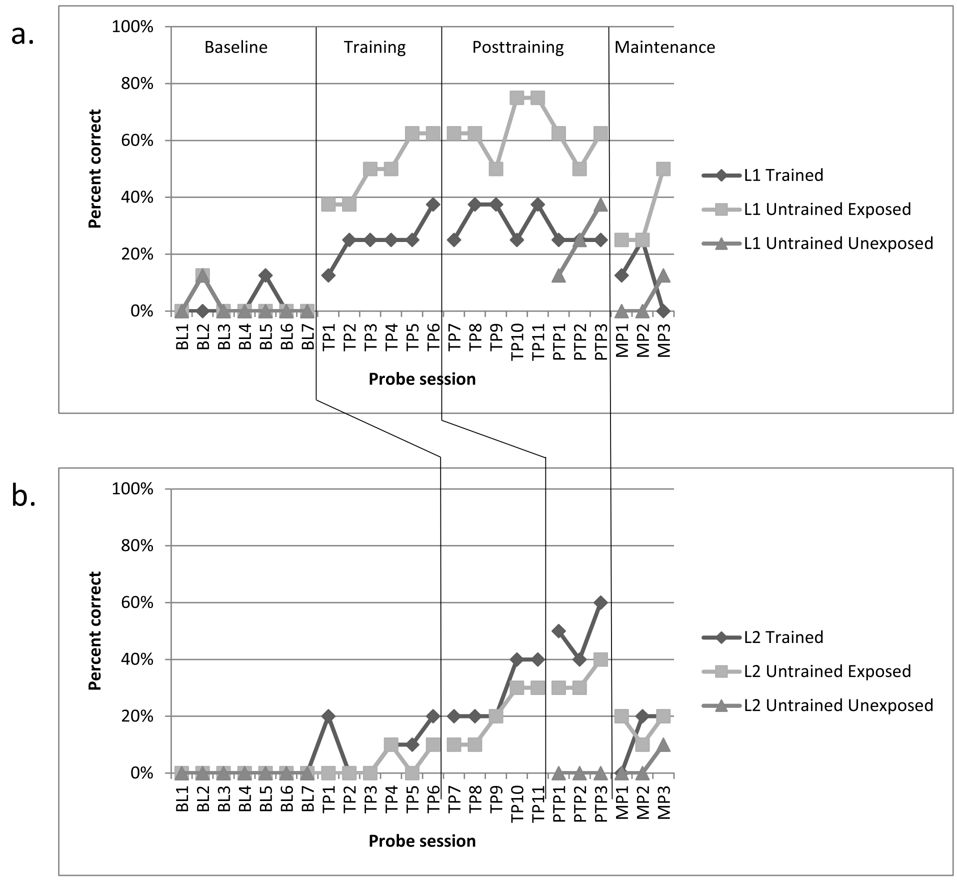
In addition to the insights obtained from the four participants who responded to this treatment, there is also useful information to be gained from the two participants who did not show improvements in naming in response to this treatment. As explored in their individual discussion sections, factors such as the ability to self-reflect and the strength of phonology and phonologic–orthographic connections appear to influence response to treatment and should be further explored.

### *Implications for Future Research*

There are a number of issues identified by this study regarding masked priming methodology for anomia treatment that need to be addressed for this treatment approach to develop further. These are in the areas of stimulus selection and masking parameters.

One issue related to stimulus selection is whether stimuli should be blocked by category or whether multiple categories should be trained at one time. The decision to block stimuli by category was made to allow assessment of within- and across-category generalization, but it is currently unclear whether this is the ideal strategy. Previous data, which showed cross-category generalization but limited within-category generalization (Silkes, 2015; Silkes et al., 2013), suggested that blocking stimuli by category may have been creating interference (Schnur, Schwartz, Brecher, & Hodgson, 2006). Inconsistent with those findings,

**Figure 14.** Accuracy on naming probes for Participant V for L1 (a) and L2 (b). L1 = first semantic category list; L2 = second semantic category list.




the participants whose data are presented here did not show cross-category generalization, and more within-category generalization occurred than had been seen previously. Further research is needed to understand the factors that influence all forms of generalization, such as stimulus selection, and how to incorporate them to maximize treatment outcomes.

Another aspect of stimulus selection that needs to be considered, based on these data, is the familiarity or relevance of the trained stimuli to each participant. Some of the variability noted between participants, and between training lists for a single participant, may have been due to differences in the semantic categories selected for training; for some, the categories selected may have been more personally relevant or more frequently encountered in their daily lives, whereas others may have been more abstract. The semantic categories used were selected based on naming performance, but options were limited for several participants who were fairly high level because there were not multiple categories with which they had enough difficulty. Using exemplars across many semantic categories in future investigations would provide greater flexibility and personalization of stimuli, allowing this potential factor to be mitigated.

Along with issues of stimulus selection, this protocol has made it clear that the problem of determining appropriate prime exposure durations must be better resolved for this treatment approach to be further developed. Each participant underwent pretesting to determine the prime exposure duration at which they were not able to reliably determine the content of the prime word, and the training protocol was initiated accordingly. For some participants, this approach worked, but for others, it did not, with primes either being ineffective over the course of the entire training regimen at that exposure duration or eventually becoming consciously visible as the participant had more experience with viewing them. Indeed, whereas some prior literature suggests that repeated exposure to well-masked primes can improve their effectiveness without yielding conscious awareness (Marcel, 1983), some have demonstrated that conscious awareness may emerge over time (Atas, Vermeiren, & Cleeremans, 2013). It is unclear at this time whether the appropriate solution is to do more extensive, or a different form of, pretesting or to do repeated visibility testing on a regular basis throughout the treatment protocol (e.g., before treatment starts each day or every few days).

These methodological problems with using masked priming raise the issue of whether visual masking is the best way to approach implicit treatment of anomia. Masking was used to facilitate implicit priming while minimizing top–down conscious influences on lexical retrieval, but the finding that poor self-reflection and a reduced ability to retain information from day to day appeared to negatively influence response to treatment, as demonstrated by PN, suggests that top–down processes are relevant despite the use of masked primes. In addition, precise control over the timing of masked prime presentation requires specific computer monitor configurations that are not widely available, raising questions about how practical masked priming could be in most clinical settings.

It is possible, however, that there are modifications of the approach reported here that could be effective and should be explored. This treatment paradigm incorporated two aspects of implicit processing: (a) masked primes and (b) repeated exposure with naming opportunities but no feedback provided. The goals of implicitly strengthening connections within lexical networks could be met with only the second implicit aspect of this protocol in play. If prime words were to be fully visible but the protocol proceeded with no, or limited, feedback, the prime stimuli would still stimulate network connections, whereas the absence of feedback would permit the participant to self-analyze and work toward correcting responses without the complication of explicitly processing and applying top–down instruction. This approach has been reported with good success (Off, Griffin, Spencer, & Rogers, 2016), so it may be worth pursuing further, in parallel with tackling the remaining issues surrounding masked priming.

## Conclusion

This study has provided further evidence to suggest that masked priming may be an effective way to improve naming ability in some people with aphasia. A number of potential individual and methodological issues remain to be explored, however, before this approach can be broadly applied in clinical settings.

## Acknowledgments

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## Appendix A

Stimuli Selected for Participant N.

| Category | T | UE | UU |
|---|---|---|---|
| L1 Sports and games | Pool | Dominoes | Fencing |
| | Snowboarding | Gymnastics | Hockey |
| | Javelin | Juggling | Horse racing |
| | Kickball | Lacrosse | Darts |
| | Ping pong | Poker | Soccer |
| | Rafting | Volleyball | Roller derby |
| | Rugby | Scrabble | Shotput |
| | Long jump | Frisbee | Tetherball |
| | Water polo | Monopoly | Rodeo |
| L2 Famous people | Bob Hope | Carol Burnett | Dick van Dyke |
| | Meryl Streep | Barbara Walters | Fidel Castro |
| | Hillary Clinton | Nancy Reagan | Bill Gates |
| | Barbra Streisand | Bill Cosby | Charlie Chaplin |
| | George Burns | Jack Nicholson | Jerry Seinfeld |
| | John Lennon | Luciano Pavarotti | Marie Osmond |
| | Michael Landon | Oprah Winfrey | Rosie O'Donnell |
| | Steve Martin | Steven Spielberg | Woody Allen |
| | Al Gore | Colin Powell | Janet Reno |
| | Mikhail Gorbachev | Nelson Mandela | OJ Simpson |

T = trained; UE = untrained, exposed; UU = untrained, unexposed; L1 = List 1 first category trained); L2 = List 2 (second category trained).

## Appendix B

Stimuli Selected for Participant P.

| Category | T | UE | UU |
|---|---|---|---|
| L1 Famous people: other | Charles Manson | Barbara Walters | Dan Rather |
| | Peter Jennings | Ted Koppel | Tom Brokaw |
| | Walter Cronkite | Al Gore | Barbara Bush |
| | Bob Dole | Colin Powell | Dwight Eisenhower |
| | Fidel Castro | George W. Bush | Gerald Ford |
| | Henry Kissinger | Janet Reno | Jesse Jackson |
| | Lyndon Johnson | Madeline Albright | Tiger Woods |
| | Mikhail Gorbachev | Nelson Mandela | Newt Gingrich |
| | Richard Nixon | Ross Perot | Saddam Hussein |
| | OJ Simpson | Dennis Rodman | Albert Einstein |
| L2 Famous people: entertainment | Alan Alda | Andy Griffith | Barbra Streisand |
| | Carol Burnett | Charlie Chaplin | Elvis Presley |
| | David Letterman | Harrison Ford | Dustin Hoffman |
| | Ed McMahon | Jerry Seinfeld | John Travolta |
| | Julia Roberts | Kirk Douglas | Liza Minnelli |
| | Marlon Brando | Meg Ryan | Mel Gibson |
| | Meryl Streep | Michael Jackson | Oprah Winfrey |
| | Ray Charles | Robin Williams | Ron Howard |
| | Sean Connery | Tom Cruise | Walter Matthau |
| | Woody Allen | Sylvester Stallone | Paul Newman |

T = trained; UE = untrained, exposed; UU = untrained, unexposed; L1 = List 1 (first category trained); L2 = List 2 (second category trained).

## Appendix C

Stimuli Selected for Participant R.

| Category | T | UE | UU |
|---|---|---|---|
| L1 Things to wear | Apron | Belt | Boot |
| | Brace | Dress | Earring |
| | Earmuffs | Glasses | Glove |
| | Hat | Helmet | Jacket |
| | Jeans | Jersey | Mask |
| | Pajamas | Pants | Sandal |
| | Scarf | Shirt | Shorts |
| | Slipper | Sock | Suit |
| | Sweater | Suspenders | Sunglasses |
| | Watch | Vest | Tie |
| L2 Tools | Razor | Ladder | Screw |
| | Needle | Wrench | Pliers |
| | Flashlight | Compass | Iron |
| | Funnel | Sponge | Nail |
| | Saw | Pen | Pencil |
| | Shovel | Hammer | Drill |
| | Knife | Fork | Paintbrush |
| | Crowbar | Level | Scissors |
| | Hose | Rake | Spoon |
| | Tweezers | Vacuum | Mop |

T = trained; UE = untrained, exposed; UU = untrained, unexposed; L1 = List 1 (first category trained); L2 = List 2 (second category trained).

## Appendix D

Stimuli Selected for Participant S.

| Category | T | UE | UU |
|---|---|---|---|
| L1 Things to wear | Apron | Blouse | Earring |
| | Brace | Clog | Glove |
| | Dress | Goggles | Hat |
| | Earmuffs | Kilt | Jacket |
| | Helmet | Lipstick | Mascara |
| | Mitten | Ring | Pin |
| | Necklace | Robe | Shawl |
| | Pajamas | Scarf | Skirt |
| | Pants | Shorts | Slipper |
| | Sandal | Sweatshirt | Suspenders |
| L2 Produce | Apricot | Asparagus | Avocado |
| | Blackberries | Parsley | Broccoli |
| | Cucumber | Cantaloupe | Coconut |
| | Grapefruit | Dates | Garlic |
| | Lemon | Grapes | Honeydew |
| | Mushrooms | Kiwi | Lime |
| | Pineapple | Scallions | Blueberries |
| | Watermelon | Pepper | Zucchini |

T = trained; UE = untrained, exposed; UU = untrained, unexposed; L1 = List 1 (first category trained); L2 = List 2 (second category trained).

## Appendix E

Stimuli Selected for Participant U.

| Category | T | UE | UU |
|---|---|---|---|
| L1 | Andy Griffith | Alan Alda | Al Pacino |
| Famous people: entertainment | Barbra Streisand | Anthony Hopkins | Dolly Parton |
| | Bill Cosby | Dick Clark | Jay Leno |
| | Eddie Murphy | Elton John | John Travolta |
| | Frank Sinatra | George Burns | Meg Ryan |
| | Gene Hackman | John Belushi | Paul Newman |
| | Jerry Seinfeld | Marie Osmond | Sean Connery |
| | Lily Tomlin | Oprah Winfrey | Steve Martin |
| | Mel Gibson | Rosie O'Donnell | Steven Spielberg |
| | Ron Howard | Tom Selleck | Whoopie Goldberg |
| L2 | Al Gore | Albert Einstein | Barbara Walters |
| Famous people: other | George Foreman | Charles Manson | Bob Dole |
| | Jesse Jackson | Dan Rather | Colin Powell |
| | Mary Lou Retton | Dennis Rodman | Fidel Castro |
| | Muhammad Ali | Henry Kissinger | Janet Reno |
| | Nelson Mandela | Martin Luther King | Jesse Ventura |
| | Newt Gingrich | Michael Jordan | Magic Johnson |
| | Ross Perot | Mikhail Gorbachev | Mother Teresa |
| | Ted Koppel | Saddam Hussein | Peter Jennings |
| | Walter Cronkite | Tiger Woods | Tom Brokaw |

T = trained; UE = untrained, exposed; UU = untrained, unexposed; L1 = List 1 (first category trained); L2 = List 2 (second category trained).

## Appendix F

Stimuli Selected for Participant V.

| Category | T | UE | UU |
|---|---|---|---|
| L1 | Albert Einstein | Barbara Bush | Dennis Rodman |
| Famous people: entertainment | Bill Clinton | Colin Powell | Martin Luther King |
| | Charles Manson | Dan Rather | Mary Lou Retton |
| | Jesse Ventura | Madeline Albright | Mother Teresa |
| | Mikhail Gorbachev | Nelson Mandela | Newt Gingrich |
| | Nancy Reagan | Prince Charles | Princess Diana |
| | Peter Jennings | Ross Perot | Saddam Hussein |
| | Walter Cronkite | Winston Churchill | Ted Koppel |
| L2 | Al Pacino | Anthony Hopkins | Brad Pitt |
| Famous people: other | Alan Alda | Barbra Streisand | Charlie Chaplin |
| | Bruce Springsteen | Charlton Heston | Danny Kaye |
| | Demi Moore | Jack Nicholson | Denzel Washington |
| | George Clooney | Kathie Lee Gifford | Jerry Seinfeld |
| | Harrison Ford | Kevin Spacey | Julia Roberts |
| | Judy Garland | Luciano Pavarotti | Kevin Costner |
| | Lily Tomlin | Meryl Streep | Meg Ryan |
| | Liza Minnelli | Ray Charles | Regis Philbin |
| | Mel Gibson | Walter Matthau | Robert Redford |

T = trained; UE = untrained, exposed; UU = untrained, unexposed; L1 = List 1 (first category trained); L2 = List 2 (second category trained).