Influence of cognitive ability on therapy outcomes for anomia in adults with chronic post-stroke aphasia

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ABSTRACT

Purpose: The relationship between cognitive abilities and aphasia rehabilitation outcomes is complex and remains poorly understood. This study investigated the influence of language and cognitive abilities on anomia therapy outcomes in adults with aphasia.

Methods: 34 adults with chronic aphasia participated in Aphasia Language Impairment and Functioning Therapy. A language and cognitive assessment battery, including 3 baseline naming probes, was administered prior to therapy. Naming accuracy for 30 treated and 30 untreated items was collected at post-therapy and 1 month follow-up. Multiple regression models were computed to evaluate the relationship between language and cognitive abilities at baseline and anomia therapy outcomes.

Results: Both language and cognitive variables significantly influenced anomia therapy gains. Verbal short-term memory ability significantly predicted naming gains for treated items at post-therapy (β=-.551, *p* =.002) and for untreated items at post-therapy (β=.456, *p* =.014) and 1 month follow-up (β=.455, *p* =.021). Furthermore, lexical-semantic processing significantly predicted naming gains for treated items at post-therapy (β=-.496, *p* =.004) and 1 month follow-up (β=.545, *p* =.012).

Discussion: Our findings suggest that individuals' cognitive ability, specifically verbal short-term memory, impacts anomia treatment success. Further research into the relationship between cognitive ability and anomia therapy outcomes may help to optimize treatment techniques.

Key words: Aphasia; Language; Cognition; Stroke.

INTRODUCTION

Anomia is a predominant feature of aphasia and as such, it is a frequent target for intervention. However, it remains unknown why some individuals with apparently similar language profiles may differentially respond to anomia therapy (Nickels, 2002b). Furthermore, it is currently not possible to predict with certainty who will respond to a particular treatment and the degree to which they will recover. It has been suggested that use of the entire cognitive system is required to participate in rehabilitation (Helm-Estabrooks, 2001, 2002) and some researchers posit that underlying cognitive deficits may account for the variable response to treatment in aphasia rehabilitation (Sinotte & Coelho, 2007). An understanding of the role of cognition in aphasia rehabilitation is important so that we may optimize existing language interventions or alternatively develop new, targeted language and cognitive interventions, commensurate with individuals' cognitive strengths and limitations (Crosson et al., 2007). In view of the increasing demands on healthcare services, it is also important that we understand which factors predict therapy success in order to identify who may respond to therapy and to facilitate optimal recruitment and distribution of therapy services (Watila & Balarabe, 2015).

Cognition is a multidimensional construct and may be defined as having five general domains, including language, attention, memory, executive functions, and visuo-spatial skills (Helm-Estabrooks, 2002). Within each of these cognitive domains, it is acknowledged that there are distinct components. For example, executive functioning incorporates skills pertaining to shifting, planning and goal-oriented behavior, whereas, attention may be further differentiated into sustained, selective and divided attention (Lezak, Howieson, & Loring, 2004; Murray, 2012). The presence of concomitant cognitive impairments in adults with post-stroke aphasia has been well documented (El Hachioui et al., 2014), and impairments in the domains of attention (Erickson, Goldinger, & LaPointe, 1996; Glosser & Goodglass, 1990; Murray, 2012; Murray, Holland, & Beeson, 1997; Sturm & Willmes, 1991; Villard & Kiran, 2015), memory (Beeson, Bayles, Rubens, & Kaszniak, 1993; Mayer & Murray, 2012; Seniow, Litwin, & Lesniak, 2009a), and executive function (Fridriksson, Nettles, Davis, Morrow, & Montgomery, 2006; Purdy, 2002) have been identified.

The presence of cognitive impairments in individuals post-stroke has been found to influence spontaneous recovery in the first 12 months' time post onset (TPO) and is significantly related to poorer functional outcomes (El Hachioui et al., 2014; Lesniak, Bak, Czepiel, Seniow, & Czlonkowska, 2008). Support for the role of general cognitive functions in aphasia rehabilitation has been provided by neuroimaging studies (Fridriksson et al., 2007; Geranmayeh, Brownsett, & Wise, 2014; Meinzer & Breitenstein, 2008; Menke et al., 2009; Raboyeau et al., 2008), with evidence suggesting that areas known to modulate memory, attention and cross-model integration may be integral to the rehabilitation process. Furthermore, in an analysis of the patient profiles of the participants in a randomized controlled trial directed to the efficacy of either semantic or phonological treatment (Doesborgh et al., 2004) van de Sandt-Koenderman et al. (2008) identified general cognitive ability at 3 to 5 months TPO as a significant predictor of treatment-induced aphasia recovery at 12 months TPO. van de Sandt-Koenderman et al. (2008) investigated the influence of linguistic, somatic, neuropsychological, psychosocial, and socioeconomic variables on the treatment-induced recovery of verbal communication, as measured by the Amsterdam Nijmegen Everyday Language Test (ANELT; Blomert, Kean, Koster, & Schokker, 1994). Individuals' attention, concentration, verbal and non-verbal memory, semantic reasoning and executive function was assessed using a comprehensive cognitive assessment battery. A single measure of individuals' neuropsychological ability was then obtained based on clinical ratings from members of the multidisciplinary team. This measure of neuropsychological ability was found to be the only variable to significantly predict changes in verbal communication on the ANELT at 12 months TPO, providing support for the general role of cognition in the treatment-induced recovery from aphasia.

Few studies have specifically investigated the influence of cognitive abilities on anomia rehabilitation outcomes in aphasia (Basso, 2003). An early study conducted by Goldenberg, Dettmers, Grothe, and Spatt (1994) found that language ability at baseline assessment significantly correlated with both spontaneous recovery and treatment success. In contrast, cognitive abilities at baseline only influenced treatment success, suggesting a specific influence of cognition in learning and therapy response. Goldenberg et al. (1994) found that two memory tests for visual information (Rey Figure recall test; Meyers & Meyers, 1995; informal semantic recall task) significantly correlated with naming gains at the completion of therapy, whereas cognitive measures of praxis, executive function and working memory did not correlate with treatment outcomes. Consistent with the findings of Goldenberg et al. (1994)., Seniow, Litwin, and Lesniak (2009b) found that visuo-spatial memory, measured using the Benton Visual Retention Test (Benton, 1974), significantly correlated with improvements in naming post-therapy, whereas executive functions did not. Together, Seniow et al. (2009b) and Goldenberg et al. (1994) provide support for the role of visuo-spatial memory in the treatment-induced recovery of naming. However, these two studies included participants in the subacute phase of recovery from stroke (TPO 2 to 6 months). Whilst the authors report differential effects of cognitive abilities during the treatment and recovery periods, it is still possible that these results may be influenced by spontaneous recovery.

Yeung and Law (2010) investigated the influence of executive function and attention, measured using the Test of Nonverbal Intelligence (TONI-3; Brown, Sherbenou, & Johnsen, 1997) and the Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002), respectively, on anomia therapy outcomes in 12 participants with chronic aphasia. The study revealed that executive function was significantly correlated with treatment gains at post-therapy and during the maintenance phase (weeks 2 to 4 post-therapy) as well as with generalization to phonologically related, untreated items. Furthermore, performance on the ANT significantly correlated with generalization to untreated items; however, it was not correlated with naming performance for treated items. Yeung and Law (2010) hypothesized that participants with strong executive function skills were better able to learn, apply and internalize naming strategies trained during therapy, and as such, had superior therapy outcomes.

Finally, a recent series of anomia therapy studies has highlighted the importance of cognitive abilities in predicting therapy outcomes (Conroy, Sage, & Lambon Ralph, 2009b; Fillingham, Sage, & Lambon Ralph, 2005a, 2005b, 2006; Sage, Snell, & Lambon Ralph, 2011; Snell, Sage, & Lambon Ralph, 2010). These studies report somewhat variable results regarding the role of executive function, self-monitoring and memory performance on anomia therapy outcomes; however, this variation may have been due to small sample size. Lambon Ralph, Snell, Fillingham, Conroy, and Sage (2010) pooled the data from four studies with comparable treatment designs (Conroy, Sage, & Lambon Ralph, 2009a; Fillingham et al., 2006; Sage et al., 2011; Snell et al., 2010) to further evaluate the role of cognitive abilities in a sample of 33 participants with aphasia. A principal component analysis revealed two factors, a cognitive and a language factor, which accounted for 34.5% and 23.1% of the variation in background measures, respectively. Measures of attention (Test of Everyday Attention, TEA; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994), executive function (Wisconsin Card Sort Task; Grant & Berg, 1993), and visuo-spatial memory (Rey Figure copy / recall; Meyers & Meyers, 1995) all loaded highly on the cognitive factor, whereas repetition and reading aloud loaded highly on the language (phonological) factor. Importantly, both factors significantly correlated with therapy outcomes for anomia at post-therapy and follow-up testing. Lambon Ralph et al. (2010) is an influential study as it is the first to demonstrate, with a relatively large sample of participants, the influence of cognitive function on anomia therapy outcomes in adults with chronic aphasia. However, the total amount of therapy provided in this research was limited (i.e., average session 20 to 40 minutes, 2 sessions per week for 5 weeks, total therapy time 3 hours 20 minutes to 6 hours 40 minutes). As such, it is difficult to determine whether an increased amount of therapy would have influenced the relationship between cognitive ability and therapy outcomes. For example, it is possible that only individuals with intact attentional abilities were able to attend to and consequently benefit from this limited dose of treatment. With an increased amount of therapy, it is possible that a different profile regarding the relative influence of cognitive abilities may emerge.

Previous research has considered the influence of cognitive impairments on treatment-induced language recovery in adults with aphasia. Several studies have investigated the effect of general cognitive abilities, measured using a composite score or battery of cognitive assessments, on treatment response (Lambon Ralph et al., 2010; van de Sandt-Koenderman et al., 2008). However, these studies do not enable consideration of the influence of individual cognitive skills and as such their clinical application may be limited. Furthermore, studies investigating the role of individual cognitive domains on treatment response have yielded mixed results. Several studies have provided support for the role of executive functions in language treatment response (Fillingham et al., 2005a, 2005b, 2006; Hinckley & Carr, 2001), whilst other studies have failed to find a significant relationship (Goldenberg et al., 1994; Seniow et al., 2009b). Likewise, evidence for the influence of attention (Hinckley & Nash, 2007; Kalbe, Reinhold, Brand, Markowitsch, & Kessler, 2005; Lambon Ralph et al., 2010) and visuo-spatial processing (Conroy et al., 2009a; Goldenberg et al., 1994; Lambon Ralph et al., 2010) on language treatment response is inconclusive. These mixed findings may be due to the influence of spontaneous recovery (Goldenberg et al., 1994; Seniow et al., 2009b), the use of small sample sizes (e.g., Conroy et al., 2009a, n = 7; Fillingham et al., 2005a, n = 7; 2005b, n = 7; 2006, n = 11) or the limited dosage of therapy provided (e.g., Lambon Ralph et al., 2010).

The present study aimed to investigate the influence of cognitive abilities on anomia therapy outcomes, as measured by naming accuracy for treated and untreated items, in adults with chronic, post-stroke aphasia. We recruited a relatively large sample of participants with chronic aphasia; provided an increased dosage of aphasia therapy (i.e., 48 hours aphasia therapy) and administered a comprehensive cognitive assessment battery. It is suggested that the integrity and recruitment of all cognitive domains is necessary for the rehabilitation process (Goldenberg et al., 1994; Seniow et al., 2009b). As such, we considered the influence of skills within each of the cognitive domains on anomia treatment response. Sufficient attention to task during training is required in order to process information (Helm-Estabrooks, 2002) and according to Keefe (1995) is necessary for cortical reorganization and recovery to occur. From a clinical perspective, sustained attention is important for individuals to be able to maintain focus for the duration of the therapy session, whilst selective attention is necessary in order to block-out external stimuli. As rehabilitation is considered a learning experience, intact memory processes are required in order to recall trained skills and behaviors (Goldenberg et al., 1994). The goal of anomia therapy is to (re)acquire verbal information and as such; specific consideration of individuals' verbal short-term memory is important (Martin & Saffran, 1999). Given that aphasia therapy resources are often provided visually (i.e., pictorially), we also considered individuals' visuo-spatial short term memory (Seniow et al., 2009b). Visuo-spatial short-term memory has the additional benefit of being able to be assessed in individuals' with severe expressive aphasia. Individuals' working memory, which involves the ability to store information short-term whilst completing a cognitive task, was also assessed. This skill is considered an important component of intelligent reasoning and as such, has implications for the therapeutic process (Seniow et al., 2009b). Finally, we considered skills pertaining to individuals' executive functioning, including measures of cognitive flexibility, concept formation and problem solving. These skills directly relate to the ability to understand the goals of intervention, self-regulate behavior, and generate and implement strategies to facilitate communication (Helm-Estabrooks, 2002; Hinckley & Carr, 2001; Seniow et al., 2009b). As baseline language ability is acknowledged as a key predictor of anomia therapy outcomes (e.g., Lambon Ralph et al., 2010; Martin, Fink, Renvall, & Laine, 2006), we also investigated the influence of two language variables, Aphasia severity and lexical-semantic processing, on anomia therapy gains.

It was hypothesized that individuals with aphasia would demonstrate variable cognitive profiles and that impairments in the cognitive domains of attention (Helm-Estabrooks, 2002; Lambon Ralph et al., 2010; Yeung & Law, 2010), memory (Goldenberg et al., 1994; Seniow et al., 2009b), and executive function (Lambon Ralph et al., 2010; Yeung & Law, 2010) would result in inferior therapeutic outcomes at post-therapy and 1 month follow-up, with respect to the confrontation naming of treated and untreated items. It was also hypothesized that individual cognitive domains would differ in their contribution to anomia treatment outcomes, with respect to the relative importance of individual cognitive domains (Helm-Estabrooks, 2002; Kalbe et al., 2005). As such, we also aimed to explore the relative impact of impairments in attention, memory and executive function on anomia therapy outcomes.

This study was conducted as part of a larger research project investigating the efficacy of the intensive, comprehensive aphasia rehabilitation program, Aphasia Language Impairment and Functioning Therapy (Aphasia LIFT). In the rehabilitation literature, there is increasing support for the provision of intensive therapy (Bhogal, Teasell, Foley, & Speechley, 2003; Bhogal, Teasell, & Speechley, 2003; Pulvermuller & Berthier, 2008); however, few studies have directly considered how cognitive ability may influence participation in intensive aphasia therapy programs. An intensive treatment schedule may place increasing cognitive demands on adults with aphasia and as such, it is possible that individuals with cognitive impairments may differentially respond to intensive versus distributed training. Consequently, a secondary aim of this study was to investigate the relationship between treatment intensity, cognitive ability and anomia therapy outcomes.

METHODS

Study design

Data for this study were collected as part of the broader Aphasia LIFT research program (Dignam et al., 2016; Dignam et al., 2015). A multiple baseline, parallel-group, pre-post-test design was employed.

Participants

Thirty-four adults (6F, 28 M; mean age 58.5 y, SD 10.9) with chronic aphasia (mean TPO 38.7 mo, SD 50.4) participated in the study (Table 1, Supplemental Table 1). Further details of these participants are reported in Dignam et al. (2015). The selection criteria for recruitment included 1) left hemisphere stroke; 2) greater than 4 months TPO; 3) residual aphasia with an aphasia severity score of less than 62.8 on the Comprehensive Aphasia Test (CAT; Swinburn, Porter, & Howard, 2004); and 4) fluent English spoken prior to their stroke. Participants were excluded from the study if they had 1) co-morbid neurological impairment (e.g., diagnosis of dementia or Parkinson's disease); or 2) severe dysarthria or apraxia of speech. A decision was made by the research team to include one participant (P33) with a borderline CAT aphasia severity score of 63.0 due to the presence of significant word finding difficulties in conversation. Participants were allocated to an intensive (LIFT; n = 16; 16 h per week, 3 weeks) versus distributed (D-LIFT; n = 18; 6 h per week, 8 weeks) treatment condition based on their geographic location, the availability of a position within the research program, and personal factors (i.e., participant availability, transport, accommodation). Two-tailed *t* tests and Fisher's exact tests were used to compare the two cohorts, LIFT and D-LIFT, at baseline. The two groups were comparable with respect to baseline demographic, language and cognitive variables ($p > .05$) (Table 1). This study was approved by the relevant institutional ethics committees and written informed consent was obtained from participants prior to participation in study procedures.

Assessment

Prior to therapy, all participants underwent a comprehensive language (Table 2) and cognitive assessment (Table 3). As therapy primarily targeted word retrieval, confrontation naming of treated and untreated items was selected as the primary outcome measure. Three baseline naming probes, consisting of 309 picture (noun) stimuli obtained from the Bank of Standardized Stimuli (Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010) were administered. Forty-eight items that the participant was unable to name correctly (i.e., 0/3 or 1/3 accuracy) were selected and randomly allocated to treated (n = 24) and untreated control (n = 24) sets. In order to provide a level of success with therapy, 12 items that the person with aphasia was able to name correctly (i.e., 2/3 or 3/3 accuracy) were selected and randomly allocated to treated (n = 6) and untreated control (n = 6) sets. Independent samples *t* tests confirmed that treated and untreated control sets were comparable with regards to baseline naming accuracy, SUBTITLE frequency (Balota et al., 2007), name agreement (Brodeur et al., 2010) and number of syllables ($p < .05$). During therapy, confrontation naming accuracy for treated and untreated items was probed after every 3 hours of impairment therapy. Outcome measures for naming accuracy of treated and untreated items were collected immediately post-therapy and at 1 month follow-up.

Language

The language battery of the CAT (Swinburn et al., 2004) was administered to evaluate participants' receptive and expressive language abilities. An estimate of participants' lexical-semantic processing was also obtained from the CAT by taking the sum of participants' raw scores from the auditory and written (single) word comprehension subtests.

Attention

Two auditory subtests from the Test of Everyday Attention (TEA; Robertson et al., 1994) were administered to evaluate participants' sustained attention (Elevator Counting) and selective attention (Elevator Counting with Distraction). The Elevator Counting with Distraction subtest also loads highly on verbal working memory.

Verbal Memory and Learning

The Hopkins Verbal Learning Test - Revised (HVLT-R; Brandt & Benedict, 2001) was administered to evaluate participants' verbal short-term memory and learning. Verbal short-term memory and working memory were also measured using the forward and reverse digit span tasks (Lezak et al., 2004), respectively. The reverse digit span task is also suggested to load on measures of attentional capacity and executive function (Baddeley & Hitch, 1974; Groeger, Field, & Hammond, 1999; Lezak et al., 2004).

Visuo-spatial Memory and Learning

The Brief Visuo-spatial Memory Test – Revised (BVMT-R; Benedict, 1997) was administered to evaluate participants' visuo-spatial memory and learning

Executive Function

Two subtests from the Delis Kaplan Executive Function System test (D-KEFS; Delis, Kaplan, & Kramer, 2001) were administered to evaluate participants' executive function skills. The D-KEFS Trails (switching) subtest is a measure of cognitive flexibility, which is considered important for higher-level skills such as multitasking, simultaneous processing and divided attention (Delis et al., 2001). The D-KEFS Sorting subtest assesses participants' concept formation and problem solving abilities.

Therapy

Therapy was administered in accordance with the principles of Aphasia LIFT outlined in Rodriguez et al. (2013). Participants each received 48 hours of aphasia therapy, which predominantly targeted word retrieval impairments. Therapy was comprised of 14 hours of impairment therapy, 14 hours of computer therapy, 14 hours of functional therapy and 6 hours of psycho-social group therapy. Impairment therapy incorporated training of 30 treated items using semantic feature analysis and phonological components analysis (Boyle, 2010; Boyle & Coelho, 1995; Leonard, Rochon, & Laird, 2008). Computer therapy reinforced training of these items using the computer software program StepbyStep (Steps Consulting Limited., 2002). Functional therapy incorporated practice of communication strategies and skills in functional communication environments, for example through the use of role-play and script training (Cherney, Halper, Holland, & Cole, 2008). Finally, group therapy employed a psycho-social approach and was based on the Aphasia Action Success Knowledge program (Grohn, Brown, Finch, Worrall, Simmons-Mackie, Thomas, unpublished data, 2012).

A comprehensive Aphasia LIFT manual was developed to promote treatment fidelity. Therapy was provided by qualified speech pathologists who received training on the treatment approaches used in Aphasia LIFT. In some instances, computer therapy was facilitated by trained speech pathology students or a trained allied health assistant under the supervision of a qualified speech pathologist. Further details regarding the therapy procedures are reported in Dignam et al. (2016) and Dignam et al. (2015).

Data Analysis

Therapy outcomes for treated and untreated items were analyzed at the individual level using the WEighted Statistics Rate of Change (WEST-ROC) method outlined in Howard, Best, and Nickels (2014). The WEST-ROC analysis takes into account individual variability during the baseline phase and compares participants' pre-therapy naming accuracy with naming accuracy at post-therapy and 1 month follow-up using a weighted one sample *t* test (Howard et al., 2014).

In order to establish a single treatment outcome score for treated and untreated items, the proportion of potential maximal gain was calculated at post-therapy and 1 month follow-up (e.g., post-therapy raw score – pre-therapy mean score)/(total number of items – pre-therapy mean score) (Lambon Ralph et al., 2010). Proportion of treatment gain at post-therapy was transformed using a reflect and logarithmic transformation (Tabachnick & Fidell, 2007). The proportion of potential maximal gain for treated and untreated items at post-therapy (treated items transformed) and 1 month follow-up, approximated a normal distribution according to the Shapiro Wilk test ($p > .05$) (Shapiro & Wilk, 1965). Multiple regression analyses were conducted to determine the relative contributions of language and cognitive variables at baseline to anomia therapy outcomes at post-therapy and 1 month follow-up. Consistent with Murray (2012), variables that were significantly correlated with treatment outcomes at post-therapy or 1 month follow-up were entered into the multiple regression analyses. Where bivariate correlations between variables was high (i.e., > .70), the variable least correlated with therapy outcome was omitted in order to prevent issues with multi-collinearity (Tabachnick & Fidell, 2007). To account for potential differences between treatment conditions, Group (i.e., LIFT/D-LIFT) was also entered into the multiple regression analyses. Prior to finalizing the multiple regression models, assumptions of normality, linearity and homoscedasticity of residuals were tested and met.

RESULTS

Thirty-two participants completed the therapy trial. Two D-LIFT participants (P29, P31) withdrew from the study prior to the completion of therapy due to acute onset illness and their data have been excluded from analyses. One D-LIFT participant (P18) did not complete the 1 month follow-up assessment due to a change in personal circumstances.

Participants' proportion of potential maximal gain for treated and untreated items at post-therapy and 1 month follow-up are reported in Table 4. A subset of this data (n = 28) are reported in Dignam et al. (2016). Twenty-six out of 32 participants made statistically significant improvements in confrontation naming accuracy for treated items at post-therapy and therapy gains were maintained for 21 out of 31 participants at 1 month follow-up. Furthermore, nine out of 32 participants made statistically significant improvements in confrontation naming accuracy for untreated items at post-therapy and this was maintained for six out of 31 participants at 1 month follow-up.

Pearson Correlations

Pearson correlation analyses between language and cognitive ability and therapy outcomes for treated and untreated items are reported in Table 5. Strong, positive relationships (i.e., $r > .70$) between the following independent variables were found: Aphasia severity and lexical-semantic processing ($r = .702$, $p < .001$); HVLT-R Total score and HVLT-R Delayed score ($r = .827$, $p < .001$); HVLT-R Total score and D-KEFS Sorting (description) ($r = .781$, $p <.001$); HVLT-R Delayed score and D-KEFS Sorting (description) ($r = .713$, $p < .001$); and BVMT-R Total score and BVMT-R Delayed score ($r = .868$, $p < .001$). Where a strong, positive correlation between two independent variables was found, the independent variable least correlated with therapy outcomes at post-therapy or 1 month follow-up, according to the Pearson correlation coefficient, was omitted from the multiple regression analysis.

Pearson correlation analyses were also used to investigate the relationship between Aphasia severity (CAT) and cognitive abilities (Supplementary Table 2) in order to account for the potential influence of language processing ability on the validity of cognitive measures.

Multiple Regression Analyses

Treated Items

Eight variables were entered into the multiple regression model to establish the relationship between language and cognitive ability and anomia therapy gains at post-therapy (Group, lexical-semantics, HVLT-R Total score, BVMT-R Total score, BVMT-R Learning score, Reverse digit span, D-KEFS Trails-Switching, D-KEFS Sorting-Total Sorts). The multiple regression model was statistically significant and accounted for 72.3% of the variance in anomia treatment outcomes at post-therapy, $R^2 = .723$, adjusted $R^2 = .626$, $F(8, 23) = 7.50$, $p < .001$ (Table 6). The beta weights indicate that verbal short-term memory and learning ability (HVLT-R Total score), $\beta = -.551$, $p = .002$, and lexical-semantic processing, $\beta = -.496$, $p = .004$, significantly contributed to therapy outcome at post-therapy, while the regression coefficient for Group (i.e., LIFT/D-LIFT) was not statistically significant, $\beta = -.190$, $p = .120$. Furthermore, squared semi-partial correlations indicate that 15.4% of the variance was uniquely accounted for by verbal short-term memory and learning ability, whereas lexical-semantic processing contributed 12.7%.

Seven variables were entered into the multiple regression model to determine the relationship between language and cognitive ability and therapy gains for treated items at 1 month follow-up (Group, lexical-semantics, HVLT-R Delayed score, BVMT-R Delayed score, BVMT-R Learning score, Reverse digit span, D-KEFS Sorting-Total Sorts). The multiple regression model was statistically significant and accounted for 59.6% of the variance in therapy gains at 1 month follow-up, $R^2 = .596$, adjusted $R^2 = .467$, $F(7, 22) = 4.63$, $p = .003$ (Table 7). Analysis of the beta weights indicate that lexical-semantic processing significantly contributed to therapy outcomes at 1 month follow-up, $\beta = .545$, $p = .012$, and squared semi-partial correlations indicate that lexical-semantic processing accounted for 13.9% of unique variance in treatment outcomes. The regression coefficients for Group ($\beta = .292$, $p = .060$) and individual cognitive variables ($p > .05$) were not statistically significant.

Untreated Items

Three variables were entered into the multiple regression model to determine the influence of language and cognitive performance on naming accuracy for untreated items at post-therapy (Group, lexical-semantics, HVLT-R Delayed score). The multiple regression model was statistically significant and accounted for 51.5% of the variance in therapy gains for untreated items at post therapy, $R^2 = .515$, adjusted $R^2 = .461$, $F(3, 27) = 9.54$, $p < .001$ (Table 8). The regression coefficient for Group was statistically significant, $\beta = .313$, $p = .030$. As such, separate multiple regression models were run for the LIFT and D-LIFT conditions. The multiple regression model for the D-LIFT group was statistically significant, $R^2 = .642$, adjusted R^2 = .587, $F(2, 13)$ = 11.65, p = .001. Performance on the HVLT-R (Delayed score) accounted for a significant proportion of the variance in naming gains for untreated items at post-therapy, β =.726, sr^2 = 28.7%, p = .007, whereas lexical-semantic processing did not (p > .05). In contrast, the multiple regression model for the LIFT condition was not significant (p = .160).

Finally, five variables were entered into the multiple regression model for untreated items at 1 month follow-up (Group, lexical-semantics, HVLT-R Delayed score, BVMT-R Delayed score, BVMT-R Learning score). The multiple regression model was statistically significant and accounted for 52.2% of the variance in naming gains for untreated items at 1 month follow-up, R^2 = .522, adjusted R^2 = .426, $F(5, 25)$ = 5.46, p = .002 (Table 9). The beta weights indicate that the HVLT-R Delayed score significantly contributed to naming gains in untreated items at 1 month follow-up, β = .455, sr^2 = 11.6%, p = .021.

DISCUSSION

This study investigated the influence of cognitive abilities, including attention, memory and executive function, and language processing ability on short and long-term anomia therapy outcomes in adults with chronic aphasia. Importantly, we found that both language and cognitive variables independently predicted therapy outcomes for anomia. With respect to the role of individual cognitive abilities, we hypothesized that impairments in the cognitive domains of attention, memory and executive function would negatively influence anomia therapy outcomes. Consistent with this hypothesis, we found that performance on measures of verbal and visuo-spatial short-term memory, working memory and executive function was significantly correlated with naming gains for treated items. Furthermore, we found that performance on the delayed memory tasks for verbal and visuospatial short-term memory and visuo-spatial learning correlated with generalization to untreated items. In contrast to our hypotheses, however, we found that attentional capacity was not correlated with therapy gains for treated or untreated items. These findings are somewhat consistent with the results of a small number of studies that have previously investigated the relationship between cognitive ability and anomia therapy outcomes in adults with chronic aphasia (Lambon Ralph et al., 2010; Yeung & Law, 2010). We further sought to explore the relative influence of individual cognitive domains on anomia therapy outcomes. We found that verbal short-term memory ability was the only cognitive skill to independently predict therapy gains for treated and untreated items, suggesting a key role of verbal short-term memory in anomia rehabilitation.

Treated Items

Memory and Learning

Helm-Estabrooks (2002) suggests that aphasia therapy is a learning experience and consequently therapy outcomes are dependent upon memory processes. The importance of memory-related structures on the success of anomia therapy has been further highlighted in neuroimaging studies conducted by Meinzer et al. (2010) and Menke et al. (2009). Consistent with these results, we found that verbal and non-verbal short-term memory (HVLT-R, BVMT-R) and working memory (reverse digit span) significantly correlated with anomia therapy outcomes and that verbal short-term memory was a significant predictor of therapy gains for treated and untreated items. Our findings suggest that the integrity of general memory processes is important in order to be able to learn and retain linguistic knowledge trained during aphasia rehabilitation. Previous research has highlighted the importance of verbal short-term memory in language learning and this skill has been found to significantly influence verbal learning in people with aphasia (Martin & Saffran, 1999). Furthermore, recent research has found that verbal learning ability, measured using a novel word learning paradigm, was significantly correlated with anomia therapy gains in adults with aphasia (Dignam et al., 2016). The results of the present study contribute to our understanding of the role of verbal short-term memory and learning in language recovery in aphasia and suggest that the short-term retention and rehearsal of linguistic information is an important skill in achieving anomia treatment gains.

Despite the potential influence of participants' language abilities, the HVLT-R (total score) was the only cognitive measure to significantly contribute to the multiple regression model for treated items at post-therapy. According to the beta values, both verbal short-term memory and lexical semantic processing independently predicted therapy gains for treated items at post-therapy. Furthermore, consideration of the squared semi-partial correlations indicates that verbal short-term memory ability accounted for 15.4% of variance in treated items at post-therapy, when controlling for the influence of other variables including lexical-semantic processing. Consequently, these findings suggest that verbal short-term memory was an important predictor of anomia treatment gains, independent of individuals' language processing ability.

Further support for the influence of short-term memory on anomia therapy outcomes is provided by the significant correlations between visuo-spatial memory, measured by the BVMT-R, and therapy gains for treated items. The positive relationship between visual-spatial memory and therapy outcomes is consistent with studies investigating treatment success and spontaneous recovery in acute/subacute aphasia (Goldenberg et al., 1994; Seniow et al., 2009b) and in treatment-induced recovery in chronic aphasia (Lambon Ralph et al., 2010). Goldenberg et al. (1994) suggests that the ability to recall linguistic information is dependent upon general memory abilities and that in adults with aphasia memory capacity may be determined using non-verbal, visuo-spatial memory tasks. Consequently, it is possible that measures of visuo-spatial short-term memory are more sensitive to the general memory capacity of individuals with aphasia, as they bypass an impaired language system. This argument further suggests that general memory capacities are important for language learning and recovery in aphasia rehabilitation.

Key differences emerged in the multiple regression models predicting therapy outcomes for treated items at post-therapy and 1 month follow-up, with respect to measures of memory. Interestingly, Total Scores from the HVLT-R and BVMT-R (i.e., immediate recall scores) were most highly correlated with anomia therapy outcomes immediately post-therapy. In contrast, the Delayed Scores from the HVLT-R and BVMT-R were most highly correlated with the maintenance of therapy gains at 1 month follow-up. These findings suggest that the cognitive mechanisms supporting memory and recall after a brief delay (i.e., 20 – 25 minutes) may also contribute to the long-term maintenance of therapy gains in aphasia rehabilitation. As such, verbal and visuo-spatial memory tests incorporating a brief delayed recall test may provide important information about individuals' ability to maintain treatment gains in the long-term.

Executive Function

Studies have demonstrated that higher order cognitive skills, including executive function, are important to be able to navigate the complex dynamics of human communication (Frankel, Penn, & Ormond-Brown, 2007; Fridriksson et al., 2006; Purdy, 2002). Furthermore, previous research suggests that executive function plays an important role in the acquisition and maintenance of anomia therapy gains (Fillingham et al., 2005b; Lambon Ralph et al., 2010; Yeung & Law, 2010). Consistent with these studies, we found that two measures of executive function, the D-KEFS Sorting (total sorts) subtest and the D-KEFS Trails (switching) subtest, significantly correlated with anomia therapy outcomes for treated items. Hinckley and Carr (2001) suggest that executive functioning may influence individuals' response to particular types of aphasia therapy. The D-KEFS Sorting subtest is suggested to measure skills including concept formation and problem solving. The therapy provided in the present study included impairment based training, using semantic feature analysis and phonological components analysis. This treatment incorporates elements of strategy, concept formation and goal oriented behavior by encouraging participants to self-generate semantic and phonological features in order to aid retrieval of the target word. The D-KEFS Trails (switching) subtest is suggested to measure skills pertaining to mental flexibility including multi-tasking and simultaneous processing. Simultaneous processing involves combining discrete stimuli in order to better comprehend the whole (Huang, 2011) and as such, may be pertinent to the generation and integration of semantic and phonological features. It is suggested that the type of impairment-based treatment employed in the current study specifically engaged the use of higher-order executive functions, including concept formation, problem solving and simultaneous processing, to facilitate word retrieval. Consequently, participants' performance on measures of executive function significantly correlated with and contributed to therapy success for treated items at post-therapy and 1 month follow-up.

Attention

Consistent with Lambon Ralph et al. (2010), we found that performance on the TEA Elevator Counting subtest was within normal limits for the majority of participants (28 out of 34 participants) and did not significantly correlate with therapy outcomes. Participants' performance on the TEA Elevator Counting with Distraction (TEA/D) subtest was more variable, with 18 out of 34 participants demonstrating impaired selective attention. In contrast to our research hypotheses and Lambon Ralph et al. (2010), we found that performance on the TEA/D did not significantly correlate with therapy gains for treated items at post-therapy or 1 month follow-up. One potential account for this result is that the dosage of therapy provided in Aphasia LIFT (i.e., 48 hours) was sufficient to generate therapy-related changes even for individuals with impaired attention. The therapy dosage provided in Lambon Ralph et al. (2010) included two 20 to 40 minute therapy sessions per week for 5 weeks. As such, it is possible that with this limited total amount of therapy, only participants with strong attentional capacities were able to engage in and benefit from treatment. In contrast, with an increased dosage of therapy provided in the present study, even individuals with impaired attentional systems responded to therapy.

Language Ability

We found that both aphasia severity and lexical-semantic processing were significantly correlated with therapy gains for treated items. Specifically, lexical-semantic processing significantly predicted therapy gains for treated items at post-therapy and 1 month follow-up. These findings are consistent with the results of previous research, which suggests that intact lexical-semantic processing is integral to the acquisition and maintenance of anomia therapy gains (Martin, Fink, & Laine, 2004; Martin et al., 2006). A number of theories have been proposed to account for the role of lexical-semantic processing in anomia treatment success (e.g., Howard, Hickin, Redmond, Clark, & Best, 2006; Martin et al., 2006; Martin & Gupta, 2004); however, this remains a complex and unresolved issue (Dignam et al., 2016). One potential account is provided by Martin et al. (2006), who suggest that impaired (input) lexical-semantic processing may result in impaired spreading activation to semantic levels of representations and consequently limit changes to the strength of connections between lexical-semantics and phonology. In addition, Martin and Gupta (2004) suggest that impaired lexical-semantic processing may disrupt semantic encoding during input and thus inhibit the learning of new verbal information. Further research to better understand the relationship between lexical-semantic processing and anomia treatment success is required.

Untreated Items

Consistent with previous research (Nickels, 2002b), we found that only a small number of participants made significant improvements in confrontation naming for untreated items at post-therapy (9 participants) and 1 month follow-up (6 participants). In a review of the anomia therapy literature, Best et al. (2013) found that treatments with a focus on strategy, particularly those that incorporated semantics, were more likely to achieve generalization than treatments that targeted specific representations. If the application of strategy is responsible for generalization, it is hypothesized that executive function would significantly correlate with gains for untreated items. However, the results of the present study do not support this hypothesis. Instead, we found that delayed recall for verbal information (i.e., HVLT-R Delayed score) significantly predicted gains for untreated items. Interestingly, Nickels (2002a) found improvements in naming accuracy for untreated items as a result of attempted naming, when no feedback or cueing was provided. Nickels (2002a) hypothesized that successful naming of a target may raise the resting level of activation, making it more likely that the target will be successfully retrieved on future presentations. Accordingly, Howard et al. (2014) suggest that in some cases improved naming for untreated items may actually be the result of repeated probing rather than generalization of word retrieval skills. It is possible that exposure to the untreated items alone may have inadvertently resulted in improved naming. Consistent with this suggestion, individuals with superior short-term memory and learning processes, as measured by the HVLT-R, were more likely to recall prior presentations of the probes and thus accurately retrieve the target items. The results of our study suggest that exposure to the probes and not generalization of underlying word retrieval skills may have resulted in improved naming for untreated items. As suggested by Howard et al. (2014), use of three stimuli sets (treated items, untreated items which are probed as frequently as treated items, and untreated items that are only assessed before and after the therapy phase) will allow further evaluation of the effects of generalization, independent of repeated naming probes.

We hypothesized that impairments in attention, executive function and memory would negatively influence anomia therapy success for treated and untreated items. However, only short-term memory ability significantly accounted for gains in untreated items and we suggest that this result may be due to repeated probing. In contrast, both short-term memory and executive function significantly correlated with therapy outcomes for treated items. This finding suggests that treatment effects were not just the result of exposure to treated stimuli, but that higher order cognitive processes were important to the therapeutic process and therapy outcomes. Furthermore, lexical-semantic processing was found to significantly influence therapy gains for treated items but not untreated items. This finding provides further support for the suggestion that alternative mechanisms are operating to support the acquisition and maintenance of treated items versus untreated items.

Treatment Intensity

We found that therapy group (LIFT/D-LIFT) was not a significant predictor of naming accuracy for treated items at post-therapy (β = -.190, *p* = .120) or at 1 month follow-up (β = .292, *p* = .060). Whilst we found a significant effect of Group for naming of untreated items at post-therapy (β = .313, *p* = .030), post-hoc power analyses conducted using G*Power 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009) indicate an achieved power of 0.43 for the LIFT condition, suggesting that this analysis was underpowered. Consequently, a larger cohort of participants is required in order to explore the relationship between treatment intensity, cognitive ability and generalization of anomia therapy outcomes.

Limitations & Future Directions

The validity of cognitive assessment in adults with aphasia, particularly assessments involving verbal processing, is often challenged due to the potential influence of language impairments on measures of cognition. In order to address this concern, we evaluated the relationship between cognitive variables and Aphasia severity (CAT) (Supplemental Table 2). Consistent with previous research (e.g., Baldo et al., 2005; Hinckley & Nash, 2007; Kalbe et al., 2005), we found significant correlations between measures of cognitive ability and aphasia severity. However, whilst cognitive tasks involving language processing components did correlate with aphasia severity, not all of these variables were found to significantly influence anomia therapy outcomes. For example, we found a strong, positive correlation between reverse digit span and aphasia severity ($r = .818$, $p < .001$), and yet, this variable only accounted for 0.1% of unique variance in therapy gains for treated items at post-therapy. If the influence of cognitive variables on anomia therapy outcomes was confounded by language processing abilities, we would expect that cognitive variables with a strong correlation with aphasia severity, such as reverse digit span, would emerge as significant predictors; however, this was not the case. Furthermore, consideration of squared semi-partial correlations indicate that cognitive ability, specifically verbal short-term memory, accounted for a significant proportion of variance in treatment gains independent of lexical-semantic processing ability. Finally, we found significant, positive correlations between cognitive measures with limited verbal demands, such as the BVMT-R, and aphasia severity, which suggests that this relationship is not solely governed by the language processing requirements of the assessment. Thus, our results provide support for the interpretation that cognitive abilities influenced anomia therapy outcomes, independently of language processing ability.

This study specifically evaluated the influence of language and cognitive abilities on anomia therapy outcomes; however, stroke-related (i.e., lesion site and size) and demographic variables may also influence recovery and treatment response (Marshall & Phillips, 1983; Meinzer et al., 2010; Plowman, Hentz, & Ellis, 2012; Watila & Balarabe, 2015). Furthermore, metacognition plays a critical role in the learning process and as such, may influence therapy outcomes (Toppino, Cohen, Davis, & Moors, 2009). Consistent with this suggestion, Fillingham et al. (2005a, 2005b) found that self-monitoring and participant awareness were significant predictors of anomia treatment success. Finally, personal factors, such as level of motivation and support, are important to the therapeutic process and may influence individuals' ability to achieve therapy gains. Further research investigating factors influencing treatment-induced recovery are required in order to advance models of rehabilitation and to establish clinically useful predictors of aphasia therapy response.

Finally, it is acknowledged that the therapy provided, Aphasia LIFT, was a comprehensive therapy program, which incorporated a combination of impairment, functional, computer and group-based training. Although impairment and computer-based therapy aimed to directly remediate the naming of treated items it is possible that therapeutic response may have been influenced by additional therapy components. As such, further research investigating the influence of cognitive domains on anomia therapy outcomes, whilst controlling the treatment approaches employed, is required.

Summary & Conclusions

This study provides evidence that both cognitive and language ability at baseline may significantly influence naming gains for treated and untreated items in response to aphasia therapy. Specifically, our findings provide support for the influence of verbal short-term memory and lexical-semantic processing on confrontation naming gains for treated items. This study advances our understanding of the cognitive mechanisms subserving treatment success in aphasia rehabilitation and the findings have important implications for clinical practice. Consideration of individuals' cognitive ability, specifically verbal short-term memory, may be helpful in determining individuals' suitability for therapy and in predicting therapy response. Furthermore, consideration of individuals' cognitive profile may help to develop more targeted language interventions, commensurate with individuals' cognitive strengths and weaknesses.

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Table 1. Participant profiles at baseline assessment.

Variable	**LIFT**	**D-LIFT**	***p* value**
Sample size	16	18	
Sex	2F, 14M	4F, 14M	.66
Age (SD), y	56.9 (10.3)	60.0 (11.5)	.41
Handedness (EHI), n			
Right	15	16	>.99
Left	1	2	
Location of Stroke (left hemisphere), n	16	18	
Time Post Onset (SD), mo	47.3 (49.3)	31.1 (51.4)	.36
Aphasia Severity (CAT)	51.6 (6.4)	52.3 (5.3)	.75
Lexical-semantics	49.6 (9.3)	49.6 (12.7)	.99
Baseline Naming	108.3 (78.3)	136.4 (71.5)	.28
TEA	6.6 (0.8)	5.9 (1.4)	.08
TEA/D	5.9 (3.4)	4.0 (2.5)	.08
HVLT/T	12.9 (7.9)	12.8 (6.1)	.97
HVLT/D	2.9 (3.2)	4.1 (3.1)	.32
BVMT/T	16.1 (9.3)	15.1 (8.4)	.74
BVMT/D	5.8 (3.5)	6.6 (4.0)	.54
BVMT/L	2.8 (1.8)	3.7 (2.7)	.25
Digit span (forward)	4.4 (2.3)	4.1 (1.7)	.64
Digit span (reverse)	2.8 (1.7)	2.9 (1.7)	.74
D-Kefs Trails (switching)	3.6 (2.9)	2.7 (2.4)	.34
D-Kefs Sorting (total sorts)	6.6 (2.2)	6.3 (2.2)	.65
D-Kefs Sorting (description)	15.9 (13.6)	12.4 (10.3)	.40

Note. N = sample size; LIFT = Intensive therapy condition; D-LIFT = Distributed therapy condition; EHI = Edinburgh Handedness Index; CAT = Comprehensive Aphasia Test; TEA = Test of Everyday Attention (elevator counting subtest); TEA/D = Test of Everyday Attention with distraction (elevator counting with distraction subtest); HVLT/T = Hopkins Verbal Learning Test (total score); HVLT/D = Hopkins Verbal Learning Test (delayed score); BVMT/T = Brief Visuo-spatial Memory Test (total score); BVMT/D = Brief Visuo-spatial Memory Test (delayed score); BVMT/L = Brief Visuo-spatial Memory Test (learning score); D-KEFS Trails (switching) = Delis-Kaplan Executive Function System Test (trail making test, number-letter switching scaled score); D- KEFS Sorting (total sorts) = Delis-Kaplan Executive Function System Test (sorting test, confirmed sorts raw score); D-KEFS Sorting (description) = Delis-Kaplan Executive Function System Test (sorting test, description raw score).

Table 2. Participant language profiles at baseline assessment.

ID	Group	CAT Spoken Comp (56)	CAT Written Comp (59)	CAT Repetition (59)	CAT Naming (62)	CAT Reading (57)	CAT Writing (57)	CAT Severity (62.9)	Lexical-Semantics (60)	Mean Baseline Naming
1	LIFT	**61**	**65**	**66**	60	**59**	**61**	61.6	59	204.7
2	LIFT	**59**	55	56	53	51	52	53.7	55	109.7
3	LIFT	51	47	45	43	47	48	46.8	47	20.3
4	LIFT	46	46	43	35	42	49	45.1	45	5.3
5	LIFT	44	31	56	46	42	42	43.5	27	55.3
6	LIFT	**59**	56	53	55	55	56	54.9	56	118.0
7	LIFT	53	**60**	58	57	54	**58**	57.1	56	103.3
8	LIFT	55	57	52	62	50	**60**	56.8	59	216.3
9	LIFT	**60**	51	53	55	46	49	53.5	56	217.3
10	LIFT	46	41	45	42	44	44	43.9	35	30.0
11	LIFT	44	43	47	54	49	48	48.5	40	110.0
12	LIFT	**57**	53	**61**	60	57	**62**	59.1	55	219.0
13	LIFT	50	48	48	47	38	47	45.8	51	32.0
14	LIFT	50	51	54	57	50	49	52.0	56	140.3
15	LIFT	**61**	57	**72**	59	56	56	60.5	54	148.7
16	LIFT	41	46	39	40	46	48	43.5	43	3.0
17	D-LIFT	30	35	46	47	46	39	40.5	10	34.3
18	D-LIFT	**63**	**63**	45	56	50	57	54.3	58	156.7
19	D-LIFT	36	51	42	43	45	50	45.9	47	16.3
20	D-LIFT	45	45	46	49	53	45	48.4	46	43.0
21	D-LIFT	56	50	51	56	50	52	52.8	51	161.7
22	D-LIFT	56	51	52	55	51	47	50.4	55	205.3
23	D-LIFT	51	37	**72**	50	46	51	51.4	28	78.0
24	D-LIFT	**61**	58	57	53	54	**58**	56.3	56	157.7
25	D-LIFT	50	53	49	54	48	51	50.9	56	169.0
26	D-LIFT	56	52	52	55	53	50	52.1	54	153.7
27	D-LIFT	50	46	**60**	48	50	54	51.1	42	45.0
28	D-LIFT	**60**	**62**	53	54	48	54	54.6	56	124.7
29*	D-LIFT	**62**	**62**	53	59	50	**65**	60.6	56	268.0
30	D-LIFT	**60**	56	59	58	53	57	55.6	60	206.7
31*	D-LIFT	**58**	56	52	56	47	**69**	56.2	60	181.7
32	D-LIFT	45	48	48	53	49	48	46.5	45	104.7
33	D-LIFT	**59**	57	**60**	**64**	**66**	**69**	**63.0**	54	227.0
34	D-LIFT	48	54	47	52	48	49	50.9	58	122.3

Note. ID = participant identification number; LIFT = Intensive therapy condition; D-LIFT = Distributed therapy condition; CAT = Comprehensive Aphasia Test; (score) = CAT cut-off for non-aphasic performance; **Bold** = scores above cut-off; SS = Semantic impairment; POL = Phonological impairment; SS-POL = impairment in mapping semantics to phonology; * withdrew from study.

Table 3. Participant cognitive profiles at baseline assessment.

ID	**Group**	**TEA** *(max = 7)*	**TEA/D** *(max = 10)*	**HVLT/T** *(max = 36)*	**HVLT/D** *(max = 36)*	**BVMT/T** *(max = 36)*	**BVMT/D** *(max = 36)*	**BVMT/L** *(max = 12)*	**Digit Span** *(forward)*	**Digit Span** *(reverse)*	**D-KEFS Trails** *(switching)*	**D-KEFS Sorting** *(total sorts)*	**D-KEFS Sorting** *(description)*
1	LIFT	**7**	**10**	12	1	14	2	0	7	5	3	6	23
2	LIFT	**7**	**5**	9	2	13	5	1	7	2	2	7	26
3	LIFT	**7**	4	9	na	13	4	5	6	3	1	6	0
4	LIFT	**7**	**10**	2	1	19	9	6	2	2	8	6	6
5	LIFT	**6**	4	10	0	0	0	0	5	2	1	2	0
6	LIFT	**6**	2	22	6	13	3	5	5	3	2	6	21
7	LIFT	**7**	**8**	20	5	27	10	4	4	5	6	7	22
8	LIFT	**7**	**9**	30	11	30	8	3	4	4	7	11	36
9	LIFT	**7**	**8**	20	6	12	6	4	7	2	5	9	32
10	LIFT	4	**3**	8	0	9	4	2	2	0	1	5	0
11	LIFT	**6**	2	10	1	6	2	1	2	2	1	5	12
12	LIFT	**7**	**10**	18	5	24	8	3	7	4	9	8	30
13	LIFT	**7**	6	6	1	6	2	2	3	2	1	8	0
14	LIFT	**7**	1	10	0	21	10	4	3	2	1	7	13
15	LIFT	**7**	**10**	19	5	34	12	2	7	6	7	9	34
16	LIFT	**7**	2	1	0	16	7	3	0	0	2	4	0
17	D-LIFT	**6**	**4**	2	0	4	2	0	3	0	1	2	0
18	D-LIFT	5	**6**	23	10	30	11	3	3	4	6	9	28
19	D-LIFT	**6**	4	5	2	9	2	2	2	0	1	6	4
20	D-LIFT	2	2	7	2	15	6	2	3	2	2	3	2
21	D-LIFT	**7**	**9**	11	3	21	11	7	4	4	9	7	25
22	D-LIFT	4	4	16	5	9	4	6	2	2	1	4	11
23	D-LIFT	**6**	2	13	0	11	7	4	7	4	1	7	4

24	D-LIFT	**7**	4	8	4	19	6	1	6	3	1	8	9
25	D-LIFT	**6**	1	14	6	29	12	6	2	2	1	7	12
26	D-LIFT	**7**	**5**	14	3	15	3	5	4	2	4	7	4
27	D-LIFT	**7**	**10**	10	0	16	10	7	7	4	4	8	5
28	D-LIFT	**7**	3	14	6	17	9	4	5	4	1	6	19
29*	D-LIFT	4	1	28	9	27	11	6	3	3	1	9	34
30	D-LIFT	**7**	2	18	9	23	12	9	5	4	7	8	22
31*	D-LIFT	5	**5**	10	6	23	12	1	5	5	3	6	15
32	D-LIFT	**6**	2	11	3	3	0	0	3	0	2	4	0
33	D-LIFT	**7**	3	13	3	6	3	2	7	6	1	3	8
34	D-LIFT	**7**	**5**	13	2	7	6	2	3	4	2	9	22

Note. ID = participant identification number; LIFT = Intensive therapy condition; D-LIFT = Distributed therapy condition; **Bold** = scores above cut-off; TEA = Test of Everyday Attention (elevator counting subtest); TEA/D = Test of Everyday Attention with distraction (elevator counting with distraction subtest); HVLT/T = Hopkins Verbal Learning Test-Revised (total score); HVLT/D = Hopkins Verbal Learning Test-Revised (delayed score); BVMT/T = Brief Visuo-spatial Memory Test-Revised (total score); BVMT/D = Brief Visuo-spatial Memory Test-Revised (delayed score); BVMT/L = Brief Visuo-spatial Memory Test-Revised (learning score); D-KEFS Trails (switching) = Delis-Kaplan Executive Function System Test (trail making test, number-letter switching scaled score); D- KEFS Sorting (total sorts) = Delis-Kaplan Executive Function System Test (sorting test, confirmed sorts raw score); D-KEFS Sorting (description) = Delis-Kaplan Executive Function System Test (sorting test, description raw score).

Table 4. Individual participants' proportion of maximal potential gain for treated and untreated items.

		Treated Items Proportional Gain		Untreated Items Proportional Gain	
ID	Group	Post-therapy	Follow-up	Post-therapy	Follow-up
1	LIFT	.82*	.56*	.24	.10
2	LIFT	.43*	.27	-.02	.12
3	LIFT	.57*	.45*	-.04	.21
4	LIFT	.25	.18	.07	.04
5	LIFT	.33	.06	.11	-.10
6	LIFT	.84*	.32	.28	.38
7	LIFT	.77*	.61*	.26	.22
8	LIFT	.96*	.63*	.25	.21
9	LIFT	.87*	.78*	.45*	.45*
10	LIFT	.34*	.26*	.10	.10
11	LIFT	.51*	.23	.12	-.01
12	LIFT	.91*	.66*	.43*	.30
13	LIFT	.30	.39	-.07	.10
14	LIFT	.96*	.91*	.42	.33
15	LIFT	.83*	.58*	.11	.24
16	LIFT	.10	.03	-.01	-.01
17	D-LIFT	.21	.16	.15	.07
18	D-LIFT	.91*	na	.55	na
19	D-LIFT	.40*	.08	-.11	-.11
20	D-LIFT	.58*	.42*	.15	.24
21	D-LIFT	.95*	.80*	.26	.22
22	D-LIFT	1.00*	.95*	.67*	.43*
23	D-LIFT	.06	.06	.02	.02
24	D-LIFT	.43*	.57*	.29	.14
25	D-LIFT	.82*	.64*	.54*	.44
26	D-LIFT	.71*	.43*	.26	.22
27	D-LIFT	.77*	.63*	.05	-.05
28	D-LIFT	.81*	.76*	.60*	.40*
30	D-LIFT	.95*	.95*	.70*	.85*
32	D-LIFT	.82*	.68*	.44*	.23
33	D-LIFT	.85*	.69*	.37*	.47*
34	D-LIFT	.91*	.91*	.43*	.38*

Note. ID = Participant identification; LIFT = Intensive treatment condition; D-LIFT = Distributed treatment condition; * WEST-ROC Analysis $p < .05$.

Table 5. Pearson correlations for language and cognitive variables and therapy gains for treated and untreated items.

	Treated Items		Untreated Items	
	Post Therapy	Follow-up	Post Therapy	Follow-up
Aphasia Severity (CAT)	-.592**	.544**	.419*	.484**
Lexical-semantics	-.666**	.665**	.489**	.589**
TEA	-.084	.171	-.048	.053
TEA/D	-.204	.146	-.140	-.185
HVLT/T	-.706**	.513**	.537**	.536**
HVLT/D	-.636**	.531**	.635**	.683**
BVMT/T	-.425*	.348	.273	.312
BVMT/D	-.406*	.438*	.338	.389*
BVMT/L	-.410*	.396*	.325	.475**
Digit span (forward)	-.144	.202	.007	.159
Digit span (reverse)	-.473**	.461**	.263	.355
D-KEFS Trails (switching)	-.421*	.288	.190	.211
D-KEFS Sorting (total sorts)	-.403*	.409*	.156	.243
D-KEFS Sorting (description)	-.652**	.507**	.424*	.445*

Note. **p* < .05; ***p* < .01; CAT = Comprehensive Aphasia Test; TEA = Test of Everyday Attention (elevator counting subtest); TEA/D = Test of Everyday Attention with distraction (elevator counting with distraction subtest); HVLT/T = Hopkins Verbal Learning Test (total score); HVLT/D = Hopkins Verbal Learning Test (delayed score); BVMT/T = Brief Visuo-spatial Memory Test (total score); BVMT/D = Brief Visuo-spatial Memory Test (delayed score); BVMT/L = Brief Visuo-spatial Memory Test (learning score); D-KEFS Trails (switching) = Delis-Kaplan Executive Function System Test (trail making test, number-letter switching scaled score); D- KEFS Sorting (total sorts) = Delis-Kaplan Executive Function System Test (sorting test, confirmed sorts raw score); D-KEFS Sorting (description) = Delis-Kaplan Executive Function System Test (sorting test, description raw score).

Table 6. Multiple regression model with proportion of potential maximal therapy gain for treated items at post-therapy as the dependent variable.

	Regression Coefficient (B)	**Standard Error (B)**	**95% Confidence Interval (B)**		**Standardised Coefficient (β)**	**Squared Semi-Partial Correlations (sr^2)**	**t**	***p* value**
			Lower	*Upper*				
Group	-.110	.068	-.250	.031	-.190	.031	-1.61	.120
Lexical-semantics	-.013	.004	-.021	-.005	-.496	.127	-3.24	.004
HVLT/T	-.025	.007	-.039	-.010	-.551	.154	-3.57	.002
BVMT/T	.005	.006	-.008	.017	.134	.007	.774	.447
BVMT/L	-.017	.017	-.052	.017	-.136	.013	-1.04	.310
Digit span (Reverse)	.006	.025	-.046	.057	.033	.001	.232	.818
D-KEFS Trails	-.023	.017	-.058	.012	-.215	.023	-1.37	.183
D-KEFS Sorting	.034	.022	-.012	.079	.250	.028	1.52	.143

Note. HVLT/T = Hopkins Verbal Learning Test (total score); BVMT/T = Brief Visuo-spatial Memory Test (total score); BVMT/L = Brief Visuo-spatial Memory Test (learning score); D-KEFS Trails (switching) = Delis-Kaplan Executive Function System Test (trail making test, number-letter switching scaled score); D-KEFS Sorting (total sorts) = Delis-Kaplan Executive Function System Test (sorting test, confirmed sorts raw score).

Table 7. Multiple regression model with proportion of potential maximal therapy gain for treated items at 1 month follow-up as the dependent variable.

	Regression Coefficient (B)	**Standard Error (B)**	**95% Confidence Interval (B)**		**Standardised Coefficient (β)**	**Squared Semi-Partial Correlations (sr^2)**	**t**	***p* value**
			Lower	*Upper*				
Group	.165	.083	-.008	.337	.292	.072	1.98	.060
Lexical-semantics	.014	.005	.003	.024	.545	.139	2.75	.012
HVLT/D	.010	.018	-.028	.048	.103	.006	.569	.575
BVMT/D	.012	.017	-.023	.047	.158	.010	.730	.473
BVMT/L	<.001	.024	-.050	.050	-.002	<.001	-.010	.992
Digit span (Reverse)	.020	.028	-.038	.077	.120	.009	.715	.482
D-KEFS Sorting	-.007	.025	-.060	.046	-.056	.002	-.286	.778

Note. HVLT/D = Hopkins Verbal Learning Test (delayed score); BVMT/D = Brief Visuo-spatial Memory Test (delayed score); BVMT/L = Brief Visuo-spatial Memory Test (learning score); DD- KEFS Sorting (total sorts) = Delis-Kaplan Executive Function System Test (sorting test, confirmed sorts raw score).

Table 8. Multiple regression models for LIFT and D-LIFT with proportion of potential maximal therapy gain for untreated items at post-therapy as the dependent variable.

	Regression Coefficient (B)	Standard Error (B)	95% Confidence Interval (B)		Standardised Coefficient (β)	Squared Semi-Partial Correlations (sr^2)	t	*p* value
			Lower	*Upper*				
Combined (LIFT, D-LIFT)								
Group	.136	.059	.014	.258	.313	.094	2.28	.030
Lexical-semantics	.005	.003	-.002	.011	.233	.033	1.35	.189
HVLT/D	.033	.012	.007	.058	.456	.124	2.63	.014
LIFT								
Lexical-semantics	.005	.005	-.007	.017	.295	.056	.957	.357
HVLT/D	.014	.016	-.020	.049	.280	.051	.908	.382
D-LIFT								
Lexical-semantics	.002	.004	-.007	.011	.105	.006	.467	.648
HVLT/D	.060	.019	.020	.100	.726	.287	3.23	.007

Note. LIFT = Intensive treatment condition; D-LIFT = Distributed treatment condition; HVLT/D = Hopkins Verbal Learning Test (delayed score).

Table 9. Multiple regression model with proportion of potential maximal therapy gain for untreated items at 1 month follow-up as the dependent variable.

	Regression Coefficient (B)	Standard Error (B)	95% Confidence Interval (B)		Standardised Coefficient (β)	Squared Semi-Partial Correlations (sr^2)	t	*p* value
			Lower	*Upper*				
Group	.126	.063	-.005	.257	.290	.075	1.98	.059
Lexical-semantics	.004	.004	-.003	.012	.219	.028	1.20	.242
HVLT/D	.033	.013	.005	.060	.455	.116	2.46	.021
BVMT/D	-.004	.011	-.027	.020	-.063	.002	-.328	.746
BVMT/L	.011	.018	-.026	.048	.117	.007	.618	.542

Note. HVLT/D = Hopkins Verbal Learning Test (delayed score); BVMT/D = Brief Visuo-spatial Memory Test (delayed score); BVMT/L = Brief Visuo-spatial Memory Test (learning score).

Supplemental Table 1. Participant demographic profiles at baseline.

ID	Group	Sex	Age	TPO	Education	Occupation
1	LIFT	M	54	20	High school (Year 10)	Sales manager
2	LIFT	M	70	33	High school	Business owner
3	LIFT	M	51	9	Post-graduate degree	Accountant
4	LIFT	M	57	66	TAFE Certificate	Film maker
5	LIFT	M	50	126	High school	Maintenance business
6	LIFT	M	70	52	High school	Hospitality business
7	LIFT	M	47	24	Undergraduate degree	Engineer
8	LIFT	M	41	29	Undergraduate degree	Engineer
9	LIFT	M	68	135	Primary / Middle school	Sales representative
10	LIFT	F	41	16	Undergraduate degree	Nurse
11	LIFT	M	66	161	High school (Year 10)	Bus driver
12	LIFT	M	52	22	Post-graduate degree	Psychologist
13	LIFT	M	54	11	Trade / Apprenticeship	Training officer
14	LIFT	M	66	34	TAFE Diploma	Accountant
15	LIFT	M	52	9	Undergraduate degree	Engineer
16	LIFT	F	71	9	Diploma	Nurse
17	D-LIFT	M	76	13	High school	Banker
18	D-LIFT	M	47	9	TAFE Certificate	Arborist
19	D-LIFT	F	62	38	High school	Shop keeper
20	D-LIFT	M	71	17	High school (Year 10)	Milkman
21	D-LIFT	M	64	225	Post-graduate degree	Engineer
22	D-LIFT	M	55	23	Trade / Apprenticeship	Chef
23	D-LIFT	M	59	16	Trade / Apprenticeship	Carpet layer
24	D-LIFT	M	52	19	TAFE Diploma	Handyman
25	D-LIFT	M	56	13	Post-graduate degree	Prof. Radiology
26	D-LIFT	M	69	82	Post-graduate degree	Financial Advisor
27	D-LIFT	M	35	7	Post-graduate degree	IT Consultant
28	D-LIFT	M	58	16	TAFE Certificate	Salesman
29*****	D-LIFT	M	54	21	Trade / Apprenticeship	Mining supervisor
30	D-LIFT	M	43	14	Undergraduate degree	Quarantine inspector
31*****	D-LIFT	F	77	4	Primary / Middle school	Home duties
32	D-LIFT	M	72	22	Post-graduate degree	Professor
33	D-LIFT	F	59	12	High school (Year 10)	Administration
34	D-LIFT	F	71	7	Primary / Middle school	Hospitality

Note. ID = participant identification number; TPO = Time post onset; LIFT = Intensive therapy condition; D-LIFT = Distributed therapy condition.

Supplemental Table 2. Pearson correlations for aphasia severity and cognitive abilities.

	Aphasia Severity (CAT)
TEA	.184
TEA/D	.275
HVLT/T	$.678^{**}$
HVLT/D	$.574^{**}$
BVMT/T	$.532^{**}$
BVMT/D	$.384^{*}$
BVMT/L	.143
Digit span (forward)	$.590^{**}$
Digit span (reverse)	$.818^{**}$
D-KEFS Trails (switching)	.338
D-KEFS Sorting (total sorts)	$.501^{**}$
D-KEFS Sorting (description)	$.743^{**}$

Note. *$p < .05$; **$p < .01$; CAT = Comprehensive Aphasia Test; TEA = Test of Everyday Attention (elevator counting subtest); TEA/D = Test of Everyday Attention with distraction (elevator counting with distraction subtest); HVLT/T = Hopkins Verbal Learning Test (total score); HVLT/D = Hopkins Verbal Learning Test (delayed score); BVMT/T = Brief Visuo-spatial Memory Test (total score); BVMT/D = Brief Visuo-spatial Memory Test (delayed score); BVMT/L = Brief Visuo-spatial Memory Test (learning score); D-KEFS Trails (switching) = Delis-Kaplan Executive Function System Test (trail making test, number-letter switching scaled score); D- KEFS Sorting (total sorts) = Delis-Kaplan Executive Function System Test (sorting test, confirmed sorts raw score); D-KEFS Sorting (description) = Delis-Kaplan Executive Function System Test (sorting test, description raw score).