**Article:**

Varley, R., Cowell, P.E., Dyson, L. orcid.org/0000-0002-6430-9731 et al. (3 more authors) (2016) Self-Administered Computer Therapy for Apraxia of Speech Two-Period Randomized Control Trial With Crossover. STROKE, 47 (3). pp. 822-828. ISSN 0039-2499

https://doi.org/10.1161/STROKEAHA.115.011939

http://stroke.ahajournals.org/content/early/2016/01/21/STROKEAHA.115.011939.abstract.html?ijkey=tQmzP4NQecTXYMH&keytype=ref

# Self-administered computer therapy for apraxia of speech: a two-period randomized control trial with crossover

Rosemary Varley, PhD[1]; Patricia E. Cowell, PhD[2]; Lucy Dyson, BMedSci[2]; Lesley Inglis, PhD[2]; Abigail Roper, MMedSci[3]; Sandra P. Whiteside, PhD[2]

1. Psychology & Language Sciences, University College London, UK
2. Department of Human Communication Sciences, University of Sheffield, UK
3. Division of Language and Communication Science, City University London, UK

## Abstract

Background and Purpose: There is currently little evidence regarding effective interventions for post-stroke apraxia of speech (AOS). We report outcomes of a trial of self-administered computer therapy for AOS.

Methods: Effects of speech intervention on naming and repetition of treated and untreated words were compared to those of a visuo-spatial sham program. The study employed a parallel-group, two-period, crossover design, with participants receiving two interventions. Fifty participants with chronic and stable AOS were randomly allocated to one of two order conditions: Speech-First vs. Sham-First. Period 1 design was equivalent to a RCT. We report results for this period and profile the impact of the Period 2 crossover.

Results: Period 1 results revealed significant improvement in naming and repetition only in the Speech-First group. The Sham-First group displayed improvement in speech production following speech intervention in Period 2. Significant improvement of treated words was found in both naming and repetition, with little generalization to structurally-similar and dissimilar untreated words. Speech gains were largely maintained after withdrawal of intervention. There was a significant relationship between treatment dose and response. However, average self-administered dose was modest for both groups. Future software design would benefit from incorporation of social and gaming components to boost motivation.

Conclusion: Single-word production can be improved in chronic AOS with behavioral intervention. Self-administered computerized therapy is a promising method for delivering high intensity speech/language rehabilitation.

Clinical Trial Registration: http://orcid.org/0000-0002-1278-0601.Unique identifier: ISRCTN88245643

http://stroke.ahajournals.org/content/early/2016/01/21/STROKEAHA.115.011939.abstract.html?ijkey=tQmzP4NQecTXYMH&keytype=ref

## Introduction

Speech/language impairments following stroke are sub-categorized into aphasia, dysarthria and AOS. AOS is a disorder at the interface of language and speech production, involving breakdown in mapping from abstract linguistic representations to motor plans.[1] Typical behaviors include speech errors, loss of automaticity and fluency, and altered timing parameters.[2] In severe cases, patients may be non-verbal. Lesions causing AOS usually occur within the left cortical motor or somatosensory areas.[3] Due to the proximity of speech control regions to left perisylvian cortex, AOS often co-occurs with aphasia.

Behavioral interventions for AOS involve two broad classes of therapies: 'bottom-up' articulatory-kinematic therapies focus on individual speech sounds[4]; 'top down' interventions aim to re-establish fluent production of larger linguistic units.[5] Comparisons of outcomes for the two approaches are not conclusive.[6] Intervention research has largely employed quasi-experimental designs with non-random assignment. A meta-analysis and systematic review conclude that there is no RCT evidence in support of intervention for AOS.[4,7]

We report outcomes of an intervention for AOS combining these two therapeutic traditions. The intervention aimed to improve word production, with target forms ultimately placed in sentence frames. This approach acknowledges the common co-morbidity of AOS with aphasia, allowing both linguistic and phonetic processes to be targeted. Trials of aphasia therapies indicate that lower intensity interventions have limited outcomes.[8] Attempts to increase face-to-face therapy 'dose' can result in high attrition rates because attending multiple appointments can challenge participants.[9] Use of software programs, allowing participants to self-administer intervention, may circumvent this difficulty. A feasibility study reported that computer therapy is cost-effective and acceptable to patients with post-stroke anomia.[10]

We employed a software therapy for AOS. It involved a perceptual stage (spoken word-picture matching; auditory-written word matching; auditory lexical decision), followed by a production stage. The perceptual component aimed to consolidate form-meaning representations of target vocabulary and facilitate feedforward input to motor representations.[11] The production stage consisted of hierarchical speech activities. First, participants observed videos of word production, followed by blocks of trials requiring imagined production. The program then moved to overt word repetition with increasing delays between stimulus and response. Responses were audio-recorded by the software. The final stages involved more autonomous word production. Participants used trained words in sentence frames, followed by independent word retrieval/picture naming (for program detail[12]).

We explored the effectiveness of this intervention in a RCT with a subsequent crossover period. Participants were randomly assigned to one of two order conditions: Speech-First or Sham-First. The sham intervention was another self-administered software program with identical interfaces but minimal speech/language content, involving visuo-spatial activities; e.g., pattern matching; timed jigsaw completion. We report outcomes for the first intervention period, and descriptively profile effects of the crossover. Power calculations based on an initial pilot study[13] indicated that, for medium-to-small effect sizes (e.g., 0.5 – 0.33) and alpha = 0.05 (2-tailed), a sample size of 50 pairs of cases was required to ensure sufficient power for repeated measures comparisons (over 95% for medium effects and 80% for small effects).

Our objective was to determine effectiveness of the speech intervention in improving communicative/functional adequacy of word production in comparison to a sham intervention for chronic AOS. Two baseline measures of speech prior to intervention were recorded to evaluate behavioral stability. Participants were profiled on a range of measures to establish AOS severity and presence of comorbidities. The primary outcome measure was communicative adequacy of spoken naming. The secondary outcome measure was phonetic accuracy of words in repetition. Three word sets were developed, each containing 35 items. One set appeared in the intervention (treated). Two untreated sets consisted of matched items (phonetically similar to treated words), or control items (phonetically dissimilar). They allowed identification of generalization of treatment to similar or remote forms. Other outcome measures were collected but not reported here (repetition word duration, health economic analysis, connected speech). The primary hypothesis was: speech intervention would result in significantly greater improvement in naming adequacy than sham. Secondary research predictions were: (1) speech intervention would result in improved repetition accuracy; (2) effects of speech intervention would generalize to phonetically-related untreated forms, but not unrelated control words; (3)

speech improvements would be maintained through a no-intervention period to final assessment (18-weeks post-intervention for Speech-First; 8-weeks for Sham-First).

**Methods**

The study was granted ethical approval by an NHS panel (08/H1308/14). Volunteers gave consent to participation. Some deception was involved because participants were blinded to the sham nature of the visuo-spatial program. Participants were told that the program aimed to improve attention and memory. Participants were offered debriefing on completion of the study. It was a single center, community-based trial (Sheffield, UK). Participants self-administered interventions, supported by speech and language therapists (SLTs), in their homes.

**Participants**

Participants were recruited from community SLT services across the South Yorkshire region over a 25-month period. The inclusion/exclusion criteria were: adults with chronic AOS (at least 5-months post-onset of apraxic stroke), unilateral left hemisphere lesion(s); absence of neurodegenerative condition; premorbid competence in English; sufficient auditory/visual acuity to interact with a laptop; not receiving impairment SLT. AOS diagnosis was independently confirmed by two SLTs using standard diagnostic criteria:[2] disrupted speech intelligibility (distortions/substitutions) with intact gross oral movements; reduced speed/fluency and effortful speech (hesitations, groping, prosodic disruption). In cases of uncertainty, a third assessor evaluated behavior. All assessors were registered SLTs.

50 participants were recruited (29 male; 21 female). Figure 1 displays progression through the study. After baseline evaluation, participants were randomly allocated to Speech-First/Sham-First conditions by a researcher blind to case via block randomization (block sizes: 20-20-10). Assessors were aware of block sizes. An unpredictable allocation sequence was generated via computer randomizer. The sequence was transferred to opaque numbered envelopes, and consecutive referrals allocated to condition via these envelopes. A subsequent allocation check revealed that one participant, allocated to Sham-First, did not receive interventions in planned order. An intention-to-treat criterion was employed, and data from this participant were analyzed as per initial randomization. No stratification/minimization was employed. Subsequent comparison of baseline AOS severity, aphasia severity, age, years of education, time-post-onset, and laterality using independent samples t-tests (two-tailed; alpha=0.05) revealed no significant differences across the two order conditions (Table 1). There was a gender imbalance in the Speech-First condition, with more males than females (17 vs. 8).

http://stroke.ahajournals.org/content/early/2016/01/21/STROKEAHA.115.011939.abstract.html?ijkey=tQmzP4NQecTXYMH&keytype=ref

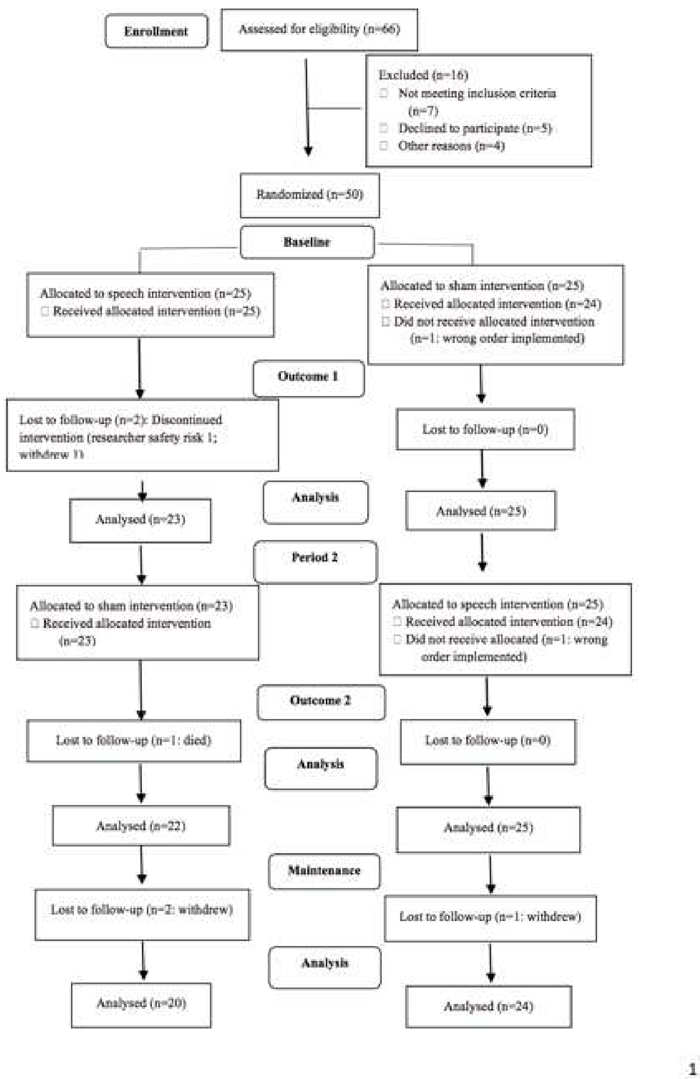



Figure 1: CONSORT diagram of participant progression through trial

Table 1. Participant characteristics across two order conditions (range; mean (SD)).

| | Speech-First | Sham-First |
|---|---|---|
| Sex | Male = 17; Female = 8 | Male = 12; Female = 13 |
| Age (years) | 28-91; M = 63 (17.2) | 36-86; M = 68 (13.4) |
| Hand/foot preference[1] | 3- +5; M = 4 (2.27) | -5 - +5 ; M = 4 (2.36) |
| Education (years formal education) | 10-19; M = 12 (2.14) | 10-17; M = 12 (2.04) |
| Aphasia severity[2] | 8-40; M = 27 (10.66) | 6-40; M = 27 (10.91) |
| AOS severity[3] | 0-11; M = 4 (3.47) | 0-9; M = 3 (3) |
| Time post-onset (months since apraxic stroke) | 5-54; M = 18 (14.17) | 5-105; M = 25 (24.72) |

[1] Laterality: pre-morbid hand/foot preference in writing; open lid; brush teeth; kick & throw ball. Right preference +1; left -1; no preference 0.
[2] Aphasia severity: composite score on lexical and grammatical probes (spoken picture naming, max. 20; spoken reversible sentence-to-picture matching, max. 20).
[3] Apraxia severity: correct syllables in non-word repetition (max. 20).

**Procedure**

Prior to randomization, there were two baseline evaluation sessions (B1, B2) to assess stability of naming and repetition behavior. The gap between baselines was 7-34 days (M = 18). There were three word sets, each containing 35 items (Supplemental Table I please see http://stroke.ahajournals.org.). One word set (Treated) appeared in intervention. Treated words, and non-matched controls, represented vocabulary of high functional value, and were roughly matched on word frequency and imageability. The two control sets did not appear in treatment and were either phonetically matched or phonetically dissimilar to treated forms (e.g., Treated: night; Matched: white; Control: house). All sets were roughly matched on word length and syllable structure. In repetition, participants repeated items following live presentation by an experimenter. Words were presented in a fixed pseudo-random order, with no phonetically-similar items appearing in sequence. Only first responses were scored. The repetition task included all 35 items from each set. Naming performance was scored on 23 word triplets (only triplets with good name agreement by healthy speakers were included to avoid treatment effects being inflated by disambiguation of images during therapy). No cues were given in either task other than orientation cues to key elements of photographs in naming. Speech data were audio-recorded for subsequent analysis by an assessor who had no participant contact and was blind to allocation and period.

Naming responses were scored as correct/incorrect (1/0). Correct responses were target words or appropriate synonyms (e.g., children-kids). Problematic responses were scored in a consensus fashion by a group of 5-6 raters, the majority of whom were blind to allocation and period. Phonetic errors were not penalized if a listener could unambiguously identify the intended target. Repetition responses were coded on a 0-7 scale (e.g., 0 = no/entirely off-target response; 6 = accurate but slow latency or lengthened duration; 7 = fast, accurate response (Supplemental Table II; please see http://stroke.ahajournals.org. for full scale). Responses scored at 6/7 were recorded as correct. An

http://stroke.ahajournals.org/content/early/2016/01/21/STROKEAHA.115.011939.abstract.html?ijkey=tQmzP4NQecTXYMH&keytype=ref

inter-rater reliability check on a subset of 558 samples was performed by a further member of the research team who was blind to period, allocation and assessor 1's ratings. The reliability sample was drawn from 16 participants with different levels of AOS severity, randomly selected across assessment points and with equal numbers from both order conditions. Spearman's Rank Correlation indicated a high level of inter-rater reliability (n=558, rho=.895, p<.0001).

Immediately after the second baseline, participants were loaned a laptop for approximately 6 weeks (Speech-First range 36-64 days; M=45, SD 5.1; Sham-First range 42-50 days; M=44, SD 1.97). Participants could access only their allocated program. A SLT researcher assisted participants with program use for initial sessions, followed by phone contact to check progress. Further support visits were arranged as needed (face-to-face visits in Period 1: Speech-First range 1- 6; M=4, SD 1.45; Sham-First 1-7; M=3, SD 1.17). Regular use of software was encouraged (once or twice a day for at least 20 minutes). The actual intensity of treatment was determined by the participant. The program recorded interactions, and compliance with recommendations could be tracked. After approximately 6 weeks, the laptop was withdrawn, and speech reevaluated (Outcome 1 (O1)).

After a 4-week rest phase, the crossover period began. The Speech-First group received sham intervention, and Sham-First, the speech program. Programs were again available for approximately 6 weeks. Laptops were then withdrawn and further reassessment completed

(Outcome 2 (O2)). Final reassessment (Maintenance (M)) took place after an 8-week no-treatment period.

**Results**

There was no significant difference in program usage across the two groups in Period 1: Speech-First range 355-1888 minutes; M=1142 (SD 439.54); Sham-First range 137-3129 minutes; M=1026 (726.17); t(46) = -0.66, p=0.512. Use of the first program tended to be higher than the second (Period 2: Speech-First range 0-2322 minutes; M=832 (677.55); Sham-First range 103-2106 minutes; M=996 (529.06)).

Statistical analyses are reported for Period 1, with naming accuracy (Table 2) and repetition accuracy (Table 3) as dependent measures. Period 2 results are profiled for treated items in Figure 2 (naming) and Supplemental Figure I (repetition) (Supplemental Table III for statistical analysis; please see http://stroke.ahajournals.org.). Comparisons explored baseline stability (B1-B2), Period 1 effects (B2-O1), and maintenance (Speech-First: O1-M; Sham-First: O2-M).

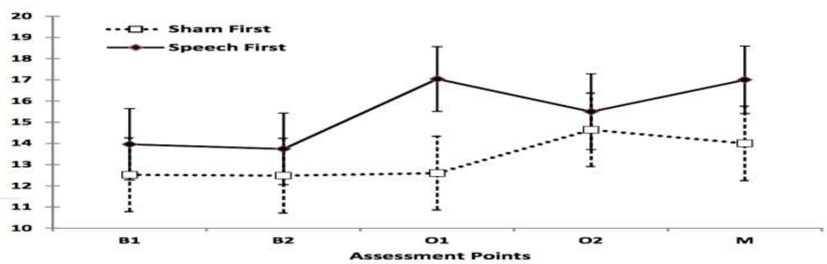
**Naming**: Means and standard errors for correctly named items are presented in Table 2. Baseline stability was investigated by ANOVA with Assessment Point (B1, B2), and Item Type (Treated, Matched, Control) as the repeated measures, and Treatment (Sham-First; Speech-First) as the between-group factor. Main effects of Item Type were significant (F=3.35, d.f.=2, 92, p<0.05) with more Treated Items correctly named than Control Items (t=3.02, d.f.=47, p<0.01;

Bonferroni corrected alpha=0.0167 for this and subsequent post hoc analyses of Item effects). There were no other significant effects. Naming accuracy was stable at baseline and comparable across treatment groups.

Table 2. Mean (± SE) naming accuracy for treated (T), matched (M) and control (C) words across assessment points by group. Medians in brackets.

| Group | Item Type | Baseline 1 (B1) | Baseline 2 (B2) | Post-intervention 1 (O1) | Post-intervention 2 (O2) | Maintenance (M) |
|---|---|---|---|---|---|---|
| Sham-First | N | 25 | 25 | 25 | 25 | 24 |
| | T | 12.52±1.74 (13) | 12.48±1.76 (14) | 12.60±1.74 (13) | 14.64±1.73 (19) | 14.00±1.76 (15.50) |
| | M | 12.32±1.73 (12) | 11.96±1.69 (14) | 12.72±1.73 (12) | 12.80±1.69 (14) | 13.25±1.76 (17) |
| | C | 11.96±1.79 (14) | 11.20±1.73 (11) | 12.16±1.75 (11) | 12.08±1.75 (13) | 12.88±1.77 (14) |
| Speech-First | N | 23 | 23 | 23 | 22 | 20 |
| | T | 13.96±1.68 (15) | 13.74±1.69 (15) | 17.04±1.53 (21) | 15.50±1.78 (19.50) | 17.00±1.59 (20.5) |
| | M | 13.17±1.72 (17) | 13.48±1.68 (15) | 14.52±1.68 (16) | 13.82±1.71 (16.50) | 15.40±1.71 (17) |
| | C | 13.48±1.60 (16) | 13.39±1.67 (16) | 15.35±1.67 (18) | 14.27±1.71 (16.50) | 15.05±1.71 (17) |

Figure 2. Mean (±S.E.) treated items correctly named in Speech-First and Sham-First conditions across assessment points.




Period 1 treatment effects were investigated using ANOVA with Assessment Point (B2, O1) and Item Type (Treated, Matched, Control) as repeated measures, and Treatment (Sham-First; Speech-First) as the between-group factor. Results revealed a main effect for Assessment Point (F=18.82, d.f.=1, 46, p<0.001) and a significant interaction between Assessment Point and Treatment group (F=5.66, d.f.=1, 46, p<0.05). The Assessment Point effect was due to better naming at O1 collapsed across Item Type and Treatment group (estimated marginal means ± S.E.s: B2 = 12.71±1.20; O1 = 14.07± 1.18). Assessment Point interacted with Treatment group with greater improvement in naming for the Speech-First (estimated marginal means ± S.E.s: B2 = 13.54±1.73; O1 = 15.64± 1.70; t=3.68, d.f.=22, p<0.01) than the Sham-First group (estimated marginal means ± S.E.s: B2 = 11.88±1.66; O1 = 12.49± 1.63; t=2.10, d.f.=24, p<0.05). The main effect of Item Type (F=7.68, d.f.=2, 92, p<0.01) and the interaction between Item Type and Treatment group (F=3.12, d.f.=2, 92, p<0.05) were also significant. Overall, Treated items were named more accurately than Matched (t=2.59, d.f.=47, p<0.014) and Control items (t=3.99, d.f.=47, p<0.001). However, only the difference between Treated and Control items was significant for both the Sham-First (t=2.60, d.f.=24, p<0.0167) and the Speech-First groups (t=3.01, d.f.=22, p<0.01). Post hoc analysis of the significant interaction between Assessment Point x Item Type x Treatment group (F=6.82, d.f.=2, 92, p<0.01) showed little change between B2 and O1 for the Treated, Matched or Control items for the Sham-First group (differences of estimated marginal means between B2 and O1 for Treated: d=0.12; Matched: d=0.76; Control: d=0.96; Bonferroni corrected alpha=0.008 for six post hoc comparisons). By contrast, increases in accuracy between B2 and O1 for the Speech-First group were larger for Treated and Control Items (differences of estimated marginal means between B2 and O1 for Treated: d=3.30; t=3.71, d.f.=22, p<0.005; Matched: d=1.04; Control: d=1.96; t=3.35, d.f.=22, p<0.005). Figure 2 shows the effect of crossover, with increased naming accuracy for the Sham-First group after exposure to the speech program (statistical analysis in Supplemental Table III).

Table 3. Means (± SE) repetition accuracy for treated (T), matched (M) and control (C) words across assessment points by group. Medians in brackets.

| Treatment Group | Item Type | Baseline 1 B1 | Baseline 2 B2 | Post-intervention 1 O1 | Post-intervention 2 O2 | Maintenance M |
|---|---|---|---|---|---|---|
| Sham-First | N | 25 | 25 | 25 | 25 | 24 |
| | T | 16.92±2.19 (19) | 17.60±2.31 (21) | 17.96±2.23 (20) | 20.64±2.09 (22) | 19.33±2.19 (21) |
| | M | 14.64±2.01 (16) | 14.92±2.20 (16) | 16.52±2.18 (19) | 17.84±2.17 (23) | 16.29±2.05 (18) |
| | C | 15.04±2.00 (17) | 16.12±2.15 (17) | 17.44±2.09 (21) | 18.60±2.16 (19) | 17.38±2.00 (18) |
| Speech-First | N | 23 | 23 | 23 | 22 | 20 |
| | T | 17.48±1.87 (20) | 18.87±2.11 (22) | 22.00±2.06 (25) | 21.55±2.13 (24.50) | 22.75±1.94 (24) |

| | | | | | | |
|---|---|---|---|---|---|---|
| | M | 16.35±1.96<br><br>(18) | 16.26±2.03<br><br>(17) | 18.22±1.89<br><br>(20) | 17.36±2.02<br><br>(17.50) | 19.95±2.27<br><br>(22.50) |
| | C | 16.96±1.99<br><br>(19) | 17.35±2.02<br><br>(19) | 18.91±1.93<br><br>(18) | 18.91±2.00<br><br>(20) | 19.75±2.21<br><br>(22.50) |

**Repetition accuracy**: Table 3 presents means and standard errors for the number of treated, matched and control items with accuracy ratings of 6 or 7. Baseline stability was investigated by ANOVA with Assessment Point (B1, B2) and Item Type (Treated, Matched, Control) as the repeated measures, and Treatment (Sham-First; Speech-First) as the between-group factor. Main effect of Item Type was significant (F=17.96, d.f.=2, 92, p<0.001) with greater accuracy for Treated compared to Matched and Control Items (T vs M: t=5.73, d.f., p<0.001; T vs C: t=3.82, d.f.=47, p<0.001). There were no other significant effects, indicating that repetition accuracy was stable across baselines and comparable across treatment groups.

Period 1 treatment effects were investigated by ANOVA with Assessment Point (B2, O1) and Item Type (Treated, Matched, Control) as repeated measures, and Treatment (Sham-First; Speech-First) as the between-group factor. Main effects for Assessment Point (F=15.18, d.f.=1, 46, p<0.001) and Item Type (F=25.32, d.f.=2, 92, p<0.001) were significant. Assessment Point effects were due to higher accuracy after intervention, collapsed across Item Type and Treatment group (estimated marginal means ± S.E.s: B2 = 16.85±1.50; O1 = 18.51± 1.45). Item Type effects resulted from significant differences among all three word sets, with the highest accuracy for Treated, followed by Control, and then by Matched items (T vs M: t=6.35, d.f.=47, p<0.001; T vs C: t=4.05, d.f.=47, p<0.001; M vs C: t=3.17, d.f.=47, p<0.001). Post hoc analysis of the significant interaction between Assessment Point x Item Type x Treatment group (F=3.98, d.f.=2, 92, p<0.05) showed relatively little change between B2 and O1 for Treated, Matched and Control items in the Sham-First group (differences of estimated marginal means between B2 and O1 for Treated: d=0.36; Matched: d=1.60; Control: d=1.32). For the Speech-First group, there were significant increases in accuracy for Treated and Matched Items (differences of estimated marginal means between B2 and O1 for Treated: d=3.13, t=3.22, d.f.=22, p<0.005; Matched: d=1.96, t=2.96, d.f.=22, p<0.008; Control: d=1.57). (See Supplemental Figure I for display of crossover effects showing an increase in repetition accuracy for the Sham-First group after exposure to the speech program; Supplemental Table III for statistical analysis).

**Maintenance effects:** Maintenance of gains in naming and repetition of Treated items were examined with paired t-tests, comparing immediate post-speech intervention performance with the maintenance assessment (Speech-First: O1 vs. M; Sham-First: O2 vs. M). For naming, there were no significant changes in the Speech-First (t=1.61, d.f.=19, n.s.) or Sham-First (t=1.49, d.f.=23, n.s.) groups, indicating maintenance of treatment gains. For repetition, there were no

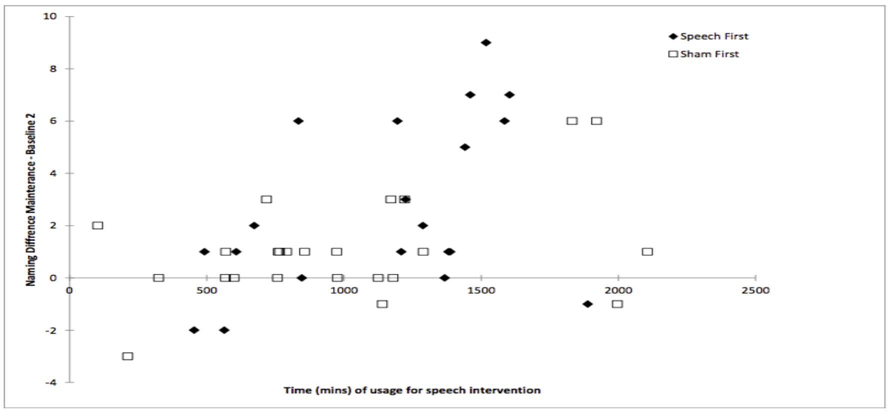
http://stroke.ahajournals.org/content/early/2016/01/21/STROKEAHA.115.011939.abstract.html?ijkey=tQmzP4NQecTXYMH&keytype=ref

changes in Speech-First (t=0.75, d.f.=19, n.s.), but a significant decrease in performance in the Sham-First (t=3.06, d.f.=23, p<0.01) group.

Dose-response correlations were computed (Figure 3). Response was measured as the difference in naming of Treated items between B2 and Maintenance. Dose was measured in terms of minutes of speech program use. The correlation for both groups was positive, indicating an increase in correctly named items as a function of increased time using the speech intervention (Speech-First: r=0.45, p<0.05; Sham-First: r=0.42, p<0.05).

Figure 3. Change in number of correctly named treated items for Speech- and Sham-First groups as a function of minutes speech program use.

http://stroke.ahajournals.org/content/early/2016/01/21/STROKEAHA.115.011939.abstract.html?ijkey=tQmzP4NQecTXYMH&keytype=ref



**Discussion**

In this two-period, crossover study we observed improvements in both naming and repetition in speakers with chronic and stable AOS impairments. Treatment effects were generally specific to trained vocabulary, with only limited transfer to phonetically-similar words in repetition accuracy. The effects of intervention were largely maintained when interventions were withdrawn; and, in the Speech-First group, this retention period was 18 weeks. There was some loss of gains in repetition accuracy in the Sham-First group, which might be due to lower baseline performance and/or the lower use of the period 2 intervention impacting upon the speech program. Treatment effects were specific to the speech program. The period 1 results, equivalent to a RCT design, revealed no significant speech change in response to the sham program. The period 2 profiles reflect the manipulation of the crossover, with increased scores on treated items in the Sham-First group for naming and repetition. Furthermore, the significant relationship between speech treatment 'dose' and response is an indicator that behavioral change might be linked to the speech intervention.

The item-specific improvement in naming is similar to that found in successful therapies for anomic aphasia.[14] One possibility is that the effects we observed resulted from lexical facilitation rather than enhancement specifically at the phonetic level. It is evident from the aphasia severity scores (Table 1) that most, but not all, participants had significant accompanying aphasic impairment. Given the strong interconnectivity between lexical and phonetic levels, top-down activation from the lexical level may enable access to motor plans. Importantly, in the face of item-specific effects, use of functionally-relevant vocabulary in therapy is essential.

The results provide evidence that computer therapy and development of programs enabling patients to self-administer interventions are important directions in rehabilitation of post-stroke speech and language disorders. This model of intervention may allow administration of high intensity therapies in a cost-effective manner. Some participants had little or no previous experience in using computers; however, design of programs with simple interfaces enabled computer novices to access interventions with SLT support. Family members were largely positive regarding the intervention, some reporting reduced burden of care in that they felt able to pursue their own activities, knowing that the participant was engaged in purposeful activity. Participants were also generally positive regarding the software, although many commented on the repetitive nature of stimulation. The ‘dose’ levels administered by participants were varied and sometimes modest. An important future direction for software design is to incorporate ‘game’ and social elements in order to maximize motivation and achieve higher usage levels. This refinement would benefit engagement with the later stages of the program in particular, which focus on use of trained words in sentence frames. Practice at this level is likely to be crucial in achieving transfer to spontaneous speech.

Acknowledgements: We thank Andrew Hardbottle and Jennifer Ryder for contributions to data collection; and Rotherham NHS Trust for assistance in participant recruitment.

This research was funded by The Bupa UK Foundation specialist grant programme. The funders had no role in design or conduct of the study.

Disclosures

Drs. Varley and Whiteside are co-authors of a commercially-available program used to treat speech impairments. They and the University of Sheffield (employers of Cowell, Dyson and Whiteside) receive royalties from sales of software. The software used in this study was a pilot version of this program.

**References**

1. Whiteside SP, Varley RA. A reconceptualisation of apraxia of speech: a synthesis of evidence. Cortex. 1998;34:221-231. doi:10.1016/S0010-9452(08)70749-4
2. McNeil MR, Doyle PJ, Wambaugh JL. Apraxia of speech: A treatable disorder of motor planning and programming. In: Gonzalez-Rothi LJ, Crosson L. Nadeau S, eds. Aphasia and Language: Theory to Practice. New York: Guilford Press 2000; 221-266.
3. Basilakos A, Rorden C, Bonilha L, Moser D, Fridriksson J. Patterns of poststroke brain damage that predict speech production errors in apraxia of speech and aphasia dissociate. Stroke. 2015;46:1561-1566. doi: 10.1161/STROKEAHA.115.009211.
4. Ballard KJ, Wambaugh JL, Duffy JR, Layfield C, Maas E, Mauszycki S., et al Treatment for Acquired Apraxia of Speech: A Systematic Review of Intervention Research between 2004 and 2012. Am J Speech Lang Pathol. 2015;24:316. doi: 10.1044/2015_AJSLP-14-0118.
5. Brendel B, Ziegler W. Effectiveness of metrical pacing in the treatment of apraxia of speech. Aphasiology. 2008;22:77–102. doi: 10.1080/02687030600965464

6. Wambaugh, JL, Nessle, C, Cameron R, Mauszycki SC. Acquired apraxia of speech: The effects of repeated practice and rate/rhythm control treatments on sound production accuracy. American Journal of Speech-Language Pathology. 2012;21:S5–S27. doi: 10.1044/1058-0360.
7. West C, Hesketh A, Vail A, Bowen A. Interventions for apraxia of speech following stroke. Cochrane Database of Systematic Reviews 2005,4:CD004298.
8. Bhogal SK, Teasell R, Speechley M. Intensity of aphasia therapy, impact on recovery. Stroke. 2003;34:987-993. doi:10.1161/01.STR.0000062343.64383.D0
9. Brady MC, Kelly H, Godwin J, Enderby P. Speech and language therapy for aphasia following stroke. Cochrane Database of Systematic Reviews 2012,5:CD000425.
10. Palmer R, Enderby P, Cooper C, Latimer N, Julious S, Paterson G, et al. Computer Therapy Compared With Usual Care for People With Long-Standing Aphasia Poststroke A Pilot Randomized Controlled Trial. Stroke. 2012;43:1904-1911. doi: 10.1161/STROKEAHA.112.650671.
11. Watkins KE, Strafella AP, Paus T. Seeing and hearing speech excites the motor system involved in speech production. Neuropsychologia. 2003;41:989-994. doi:10.1016/S0028-3932(02)00316-0
12. Whiteside SP, Inglis AL, Dyson L, Roper A, Harbottle A, Ryder J, et al. Error reduction therapy in reducing struggle and grope behaviours in apraxia of speech. Neuropsychological Rehabilitation. 2012;22:267-294. doi: 10.1080/09602011.2011.639614.
13. Cowell PE, Whiteside SP, Windsor F, Varley RA. Plasticity, permanence and patient performance: study design and data analysis in the cognitive rehabilitation of acquired communication impairments. Frontiers in Human Neuroscience. 2010;4:213. doi: 10.3389/fnhum.2010.00213.
14. Best W, Greenwood A, Grassly J, Herbert R, Hickin J, Howard D. Aphasia rehabilitation: does generalisation from anomia therapy occur and is it predictable? A case series study. Cortex. 2013;49:2345-57. doi: 10.1016/j.cortex.2013.01.005.