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Vocabulary acquisition in aphasia: Modality can matter

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Abstract

The present case study investigated modality-specific aspects of novel word acquisition in aphasia. It was prompted by recent aphasia case studies indicating great interindividual variability in the ability to learn and maintain novel words in aphasia. Moreover, two previous case studies revealed a striking effect of input modality by showing effective word learning and re-learning via visual input only (Kohen, Sola, Tuomiranta, Laine, & Martin, 2012; Tuomiranta et al., 2014). The present participant TS with chronic nonfluent aphasia and post-semantic anomia was administered novel word–referent learning tasks. In the first experiment, the learning phase included simultaneous phonological and orthographic input, while the follow-up was probed separately for spoken and written responses. In the second experiment, we studied the effect of four different input and output modality combinations on her ability to learn to name the novel items. In the first experiment, TS’s spoken naming performance during the learning phase was just within the range of healthy controls. Maintenance declined and remained outside that range during the whole 6-month follow-up. However, TS maintained the learned words better in written than in spoken naming throughout the follow-up, and in written naming, her maintenance stayed within the control’s range up to 8 weeks post-training. The second experiment indicated that the best learning outcome was achieved with orthographic input. Orthographic input combined with orthographic output resulted in fast and accurate learning of the novel words. Interestingly, TS’s test profile was opposite to her learning profile, as she repeated better than she read aloud in the linguistic background assessment. The results from the present case highlight the importance of multiple learning channels for word acquisition in individuals with aphasia. Probing the functionality of different input and output channels for learning may also prove valuable in tailoring effective treatment for persons with aphasia.

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Keywords

aphasia; word learning; modality; long-term memory; spoken naming; written naming

1. Introduction

Anomia is one of the most frequent symptoms in aphasia and consequently a significant target in treatment (Laine & Martin, 2006; p. 1; Nickels, 2002). In spite of extensive research on naming disorders, surprisingly little attention has been directed to the role of word learning ability in recovery and treatment. Basso, Marangolo, Piras, & Galluzzi (2001) suggested that novel word learning in healthy individuals can be compared to re-establishing access to familiar words in aphasia (see also Breitenstein, Kamping, Jansen, Schomacher, & Knecht, 2004). They also drew parallels between the most effective modes of word learning and re-learning. In their study, the same orthographic learning method that allowed for the most effective learning in the healthy population, also promoted the best word re-learning in the aphasic individuals. To our knowledge, only one aphasia study has made a similar comparison of learning vs. re-learning modes within an individual with aphasia (Tuomiranta et al., 2014). The present case study relates to these issues by focusing on the significance of the input/output channels for acquisition of novel active vocabulary in aphasia.

The capacity for lexical acquisition can be probed with novel word learning tasks, and if these consist of unfamiliar words and unfamiliar referents, it can be argued that they provide a relatively pure measure of the functionality of word learning mechanisms. Learning words that have never belonged to one's vocabulary requires that the learner establishes representations for a novel word form and its referent as well as a link between them. Furthermore, the novel representations need to be stored, integrated with other entries in long-term memory, and be accessible when needed for language performance (e.g. production) (Laine & Salmelin, 2010). The Complementary Learning Systems model (CLS; O'Reilly & Norman, 2002) provides a neurocognitive framework for word learning by relating it to an interaction of cortical and subcortical (especially hippocampal) structures. According to the CLS model, in the initial phase of learning, temporary associations are rapidly created between referents and their corresponding names. These associations are established as episodic memory traces in the hippocampus. For long-term maintenance of these associations, these temporary memory traces have to be consolidated and integrated with other contents in the declarative memory cortically. In contrast to novel word learning, which must be based on brain systems for lexical acquisition, re-learning of lost but familiar words in aphasia may present a mix of novel learning and priming based on re-activation /re-linking of representations that still exist but are inaccessible. Thus, while it is natural enough for anomia treatment studies to focus on familiar vocabulary, it can be more difficult to determine what mechanisms are involved in those studies.

To date, there is a large body of anomia treatment research conducted with familiar words (for a review, see e.g. Laine & Martin, 2006; and the Academy of Neurologic Communication Disorders and Sciences Aphasia Treatment Website, <http://aphasiatx.arizona.edu>). In addition, there is limited evidence that some individuals with

chronic aphasia retain an ability to learn totally novel active vocabulary (e.g. McGrane, 2006, also reported in Kelly & Armstrong, 2009; Tuomiranta et al., 2011; 2014; Tuomiranta, Rautakoski, Rinne, Martin, & Laine, 2012). One method for probing novel word learning that has been applied in these studies is the Ancient Farming Equipment (AFE) paradigm (see the review by Laine & Salmelin, 2010), which entails learning the names of real but antique concrete objects where both the objects and their names are unknown to modern generations. Previous AFE investigations of aphasic participants have thus addressed explicit learning of active vocabulary, employing learning sessions over several days to promote memory consolidation of the novel item–word pairs. The results have revealed surprisingly large variability in acquisition and maintenance of novel active vocabulary in aphasia, ranging from rather modest learning up to normal levels (Tuomiranta et al., 2011; 2014). We reported a particularly relevant case, AA (Tuomiranta et al., 2014), a 60-year-old individual with chronic aphasia and extensive left temporal lesion, who could maintain the learned words in her active vocabulary up to a half a year post training. However, this previously undetected ability was available only when the to-belearned words were presented in written form. Background testing revealed symptoms of deep dysphasia together with better preserved but not intact word reading. It was the modality-specific nature of AA's word learning ability that inspired us to systematically explore word learning in visual vs. auditory modalities in the present case.

Modality issues are also relevant for anomia therapy with familiar but inaccessible words. Orthographic and phonological cueing are regularly utilized techniques in anomia treatment, aiming to facilitate access to previously mastered but inaccessible words (Basso, 2003; p. 217; Best, Herbert, Hickin, Osborne, & Howard, 2002; Nickels, 2002) although more research has been devoted to phonological cueing effects (Best et al., 2002; Nickels, 2002). Investigations have showed diverse patterns of cueing effects in the short and long-term, leading to different assumptions on the mechanisms and levels of processing that support cueing. Bruce and Howard (1988) argued that persons with aphasia can make use of orthographic cues only if they also show the same effect for phonological cues, but later studies have identified cases that have shown orthographic cueing effects in the absence of phonological cueing effects (Howard & Harding, 1998; Lorenz & Nickels 2007). This suggests that phonological vs. orthographic cueing can exert relatively independent effects.

In cognitive neuropsychology, dissociations in the processing of familiar words in individuals with acquired language disorders have provided evidence for the fractionation of the mental lexicon into functionally separate input and output lexicons for spoken and written words (e.g. Basso, 2003; Shelton & Weinrich, 1997). Following the CLS model, these cortically supported systems are necessary both for the initial encoding of novel words and for the long-term storage of the newly created lexical representations after the hippocampal word-referent binding has occurred. Accordingly, modality-specific issues are relevant for novel word learning in aphasia as well. However, apart from the dissociation in the visual vs. auditory input modalities in novel word learning in the two cases reported by Kohen et al. (2012) and Tuomiranta et al. (2014), very little is known about the effects of input/output modalities on novel word learning in persons with aphasia. In some of the previous novel word learning investigations with aphasic participants, the to-be-learned words have been presented simultaneously auditorily and orthographically (Laganaro, Di

Pietro, & Schneider, 2006; McGrane, 2006; Tuomiranta et al., 2011, 2012, 2014). This makes it impossible to separate the contribution of auditory and orthographic systems to novel word acquisition. Two other studies have employed only auditory input but found very poor learning as measured by novel word production (Grossman & Carey, 1987; Gupta, Martin, Abbs, Schwartz, & Lipinski, 2006).

In the present case study we studied the auditory and written input/output effects during acquisition of novel active vocabulary in TS, a person with chronic aphasia and post-semantic anomia. Her written naming skills were relatively preserved compared to her spoken naming. We conducted two word learning experiments with her using the AFE paradigm. The first one addressed possible dissociations in word learning and long-term maintenance in oral vs. written naming where two previous case studies have found a dissociation (Kohen et al., 2014; Tuomiranta et al., 2014). The second experiment explored for the first time modality-specific effects in short-term word learning by systematically comparing oral vs. written input and output channels. Further evidence for modality-specific effects on word learning would highlight the importance of multiple learning channels in lexical acquisition and re-acquisition in aphasia.

2. Method

2.1 Materials

Participant TS with aphasia underwent an extensive cognitive-linguistic background assessment. The battery included the standardized Finnish version of the Boston Diagnostic Aphasia Examination (BDAE; Laine, Niemi, Koivuselkä-Sallinen, & Tuomainen, 1997b), the Finnish version of the Boston Naming Test (Laine, Koivuselkä-Sallinen, Hänninen, & Niemi, 1997a), the Finnish adaptation (Tuomiranta, Laine, & Martin, 2009) of the Temple Assessment of Language and Short-term Memory in Aphasia¹ (TALSA; Martin, Kohen, & Kalinyak-Fliszar, 2010), a semantic odd-one-out judgment task using pictures and words (Laine, Kujala, Niemi, & Uusipaikka, 1992), and the Corsi Block Tapping Task (De Renzi & Nicelli, 1975).

After Experiment I, the background assessment was complemented with the BNT (first orally and then in writing, on separate days), the Finnish version of the Token test (De Renzi & Faglioni, 1978) separately with auditory vs. written instructions, the Trail Making Test (TMT; Poutiainen, Kalska, Laasonen, Närhi, & Räsänen, 2010), repetition and oral reading of words and pseudowords varied for word length and frequency (Renvall, Laine, Laakso, & Martin, 2003), and a 50-picture classification task (Laine et al., 1992).

The control participants were interviewed and tested to confirm that they were healthy with no difficulties in language processing, reading, writing or verbal short-term memory. The tests included the standardized Finnish version of the Boston Naming Test (BNT; Laine et

¹Temple Assessment of Language and Short-term Memory in Aphasia (TALSA) probes language comprehension and production with a focus on short-term memory processes. Some of the language tasks systematically manipulate short-term memory load by varying the number of items that need to be kept active in memory. Other tasks systematically vary the interval between stimulus presentation and response (unfilled or filled with counting aloud random numbers) and interval length (immediate or delayed response). In addition, the TALSA contains digit, word and pseudoword span tasks. Part of the span tasks can be administered utilizing two response modes: either as an oral repetition task or as a pointing task with a grid of digits or pictures.

al., 1997a), phonological and semantic fluency tasks, a narration task, a semantic odd-one-out task using pictures and words (Laine et al., 1992), and verbal span tasks of the Finnish version of the TALSA (Tuomiranta et al., 2009).

2.2 Training stimuli

Experiment I included a set of 20 black-and-white line-drawings of unfamiliar objects and their equally unfamiliar bi- or trisyllabic real names (see Fig. 1A for sample item). The objects were drawn from the Ancient Farming Equipment (AFE) item pool. The same set was utilized in three earlier studies (Tuomiranta et al., 2011; 2012; 2014). Half of the objects carried a short description of their usage in order to probe incidental semantic learning (not reported in the present study that focuses on word form learning).

Experiment II included four sets of 15 AFE object drawings and bisyllabic pseudonyms paired with them. The sets were balanced with regard to visual complexity of the drawing (see Grönholm, Rinne, Vorobyev, & Laine, 2005) as well as average bigram frequency and CV structure of the names (sample item in Fig. 1B).

2.3 Participant TS with aphasia

Participant TS was a 49-year-old right-handed female with approximately 14 years of education and work background as a receptionist. She was monolingually Finnish-speaking, but had also learned Swedish and English in school and had been able to use these languages on a functional level in her work prior to a left middle cerebral artery infarct 7 years before the present investigation. The infarct had resulted in global aphasia and right-sided hemiparesis. Her hemiparesis was still present during the present investigation.

MRI scan at 6 days post-onset (see Fig. 2) showed an extensive infarct in the left hemisphere including the entire temporal cortex, parts of the parietal cortex with somatosensory regions and extension to motor areas, insular cortex, and the inferior frontal gyrus. Most of the opercula was destructed including both Broca's and Wernicke's areas. This was in line with TS's initial global aphasia. In addition, an ischemic bleed more recent than the initial infarct was seen in the left nucleus lentiformis. The ischemia reached the left hippocampal region.

Hearing was not tested formally but TS had no subjective complaints and her performance during background testing did not suggest evident hearing impairment. TS had received speech and language therapy up to 2 years 6 months prior to the start of the present experiments.

At the time of this study, TS's language profile corresponded to Broca's aphasia with a severity rating of 3 (BDAE; Table 1) but both language production and comprehension were severely impaired. Nonetheless, TS could discuss familiar topics with support from the communication partner. Her spontaneous speech was non-fluent and consisted of relatively short utterances (max. 5 words) with restricted syntax and occasionally only content words. She exhibited mild symptoms of apraxia of speech (AOS) with slightly affected prosody, slowed articulation and often some weakly articulated consonants. Additions, omissions and substitutions of phonemes were frequent in her speech.

In naming, TS succeeded better with shorter than longer words (TALSA; $\chi^2 (2, N = 90) = 27.10; p < 0.001$). Her naming accuracy was also affected by word frequency, with frequent words being easier than infrequent ones (TALSA; $\chi^2 (2, N = 90) = 27.10; p < 0.001$). TS's performance in the semantic fluency task stands out as relatively stronger (90th percentile) than the other naming tasks of the BDAE (50th – 60th percentile), possibly due to TS's effective cognitive strategies. The BNT with spoken responses was administered prior to Experiment I and repeated after Experiment I. The BNT with written responses also was administered after Experiment 1. TS's spontaneous naming score varied between 18–25 /60 for oral naming, and was 27 /60 in written naming. TS's naming errors were mostly nonwords phonologically closely related to the targets. Also, she produced some semantically related errors, as well as some circumlocutions. Also in the BNT, a negative correlation between naming success and word length was found (oral naming $r(60) = -0.37; p = 0.003$; written naming $r(60) = -0.44; p = 0.001$), while word frequency failed to affect naming success. In the BNT, cueing helped TS with 8 out of 14 (57 %) items in oral naming and 2 out of 7 (29 %) items in written naming responses (the cued targets where comparable across the test modality in terms of length and frequency).

TS was able to repeat words and even some three-word familiar sentences (e.g. Tulin töistä kotiin "I came home from work"). Word repetition (Table 2) was significantly affected by word frequency (high > low) (Fisher's exact test $p = 0.046$) but not by word length ($p = 0.09$). Pseudoword repetition resulted in errors especially when short-term memory load increased through administration of longer and/or filled intervals between stimulus and response). In immediate repetition of pseudowords, there was a statistically significant effect of word length ($\chi^2 (2, N = 90) = 6.48; p = 0.04$). TS read aloud words slowly, showing an effect of word frequency on reading accuracy ($\chi^2 (2, N = 90) = 7.91; p = 0.02$). Reading aloud pseudowords was very challenging to her. Neither word length ($\chi^2 (2, N = 90) = 1.67; p = 0.43$) nor pseudoword length ($\chi^2 (2, N = 90) = 4.32; p = 0.12$) affected TS's reading accuracy. Based on chi square tests, TS repeated words and pseudowords better than she read them aloud (words $\chi^2 (1, N = 90) = 10.61; p = 0.01$; pseudowords $\chi^2 (1, N = 90) = 63.55; p < 0.001$).

TS could write single words from dictation or in naming but tended to make spelling errors especially in relation to quantity. Her narrative writing was agrammatic with no complete sentences. Writing was something that TS had actively and independently trained during the last few years. Her self-report of the development in writing skills was very positive.

TS showed auditory comprehension difficulties during the assessment (see Tables 1 and 2 for her performance in the Complex ideational material of the BDAE and the Token Test), and also in everyday discussions when longer phrases and complex syntax were used. Her comprehension of single words was good and not affected by greater short-term memory load (longer and/or filled intervals in the Finnish version of the TALSA). In reading, she could match single words with pictures and comprehend short sentences. Reading became more uncertain at paragraph level (BDAE) and in syntactically complex instructions (a written version of the Token Test without time limit).

The background assessment suggested that TS's lexical-semantic abilities were preserved relatively well. She made two errors in the 50-picture classification task (Laine et al., 1992). In the semantic odd-one-out tasks, she performed outside the range of a small group of healthy elderly only in one task (17 out of 20 in the word version of the odd-one-out task with a normal range of 18–20).

TS's verbal span performances varied between 1–4 items while her visuo-spatial span in the Corsi Block Tapping Task was 5 items. In the TMT, TS could not perform the alphabet trail. In the number trail (TMT-A) she performed well, being at the 70th percentile. TS's executive skills, problem solving, and cognitive control were not assessed formally but appeared functional during the sessions. TS was careful to avoid cognitive fatigue and therefore all sessions were kept relatively short (max. 45 minutes).

The results presented above indicate that TS's profile of spared and impaired abilities could be attributed mainly to a post-semantic impairment, which may have involved both the phonological output lexicon and the programming of phonemic sequences. Given TS's relatively well spared lexical semantic skills, her occasional semantic naming errors could stem from impaired access from the lexical-semantics to the phonological output lexicon. The frequency effect in naming, repetition, and reading aloud, as well as by the formal paraphasias that she occasionally produced in naming, point to an impairment of the phonological output lexicon (Goldrick & Rapp, 2007; Whitworth, Webster, & Howard, 2005). An additional impairment of the programming of phoneme sequences for output is suggested by her many phonological errors and often successful repair sequences, as well as the length effect in naming and pseudoword repetition (Laine & Martin, 2006; Whitworth et al., 2005). Moreover, TS had a post-semantic impairment in writing including the programming of grapheme sequences: she made orthographic errors that led to nonwords and showed a length effect in written naming.

2.4 Control participants

The control group for Experiment I included six healthy monolingual Finnish-speaking participants (age range 50–64; one male; range of formal education 10–13 years). The pretraining screening and interview suggested no developmental impairments or deviances in the language performance of any of the control participants. All participants received information of the study in spoken and written form and gave their informed consent. The investigation had approval from the Ethics Committee of the Hospital District of Southwest Finland.

2.5 Experimental design

Experiment I: The first experiment followed the design of three previous investigations (Tuomiranta et al., 2011; 2012; 2014) and utilized the AFE learning paradigm. All participants were to learn to name 20 novel objects with 20 novel names. A pretest ascertained that the items and their names indeed were unfamiliar to the participants (knowing up to one was deemed as acceptable but that item would be left out of the analysis). There were four approximately one-hour long computer-aided training sessions involving explicit learning of the novel object names (see Fig. 3A for the timeline). TS's

four training sessions took place during a period of 10 days and the control participants' during 8–12 days. The participant saw a line-drawing of one object at a time coupled with its name in written and spoken form for 12 seconds. The participant was to repeat aloud each name. Half of the items also carried a semantic description (spoken aloud and shown in writing) but the participants were told only to learn the names. There were five pseudo-randomized training rounds in each training session, the last round always being a pointing-and-naming task where the participants saw all items at the same time and were prompted to name each item in a pseudorandomized order. In case of no response or an error, the investigator gave the correct word in spoken form.

Acquisition of the novel vocabulary was measured by visual confrontation naming at the start of training sessions 2–4. Naming performance was then followed up at one day, one week, four weeks, eight weeks and six months post-training, with no further exposure to the stimuli after the training period. During the follow-up, participants were cued with the first syllable in case of erroneous or no response in the naming test. As participant TS indicated that she would be able to respond in writing, her naming skills were always measured twice during each follow-up session: first in oral naming with the computer keyboard covered and ten minutes later in writing by hand (the control participants were only administered an oral naming task). In addition to naming, we also administered a visual recognition test of the 20 trained items and 20 untrained distractors, and measured incidental learning of the semantic definitions with an oral/written recall task. However, here we only report the naming measures.

Experiment II: The second experiment included only participant TS with aphasia. In this task, input (auditory or orthographic) and output (spoken or written) conditions for novel word learning were factorially combined. The four combinations were presented in the following order: auditory–written (AUD–WRI), orthographic–spoken (ORT–SPO), auditory–spoken (AUD–SPO), and orthographic–written (ORT–WRI). Each combination was trained during two consecutive days with a one week interval between the conditions (see Fig 3B). For each condition, there was a different training set of 15 bisyllabic pseudowords combined with 15 novel objects. The training sets were comparable by bigram frequency, CV structure, and visual complexity of the pictured objects. In the auditory input conditions, TS saw a picture on computer screen and listened to the name spoken once by the investigator. The orthographic input conditions had the name written under the picture, appearing for one second in order to have an exposure time comparable to the auditory input. Spoken output called TS to name the picture orally while written output required her to write the name on a blank paper. The modality of the naming test that measured learning corresponded to the output modality during training.

There were always four training rounds per training session. Naming rounds that probed the learning outcomes of TS were administered after the second and the final fourth training round. An additional retention test initiated the second session. During all training, the computer keyboard was covered and TS was prompted to not “write with a finger”, or, during written output conditions, to not say the words aloud. As TS’s cognitive control was good, she did not require many reminders of these restrictions.

2.6 Data analysis

Spoken responses from the background tests as well as from the word learning experiments were transcribed from audio files and analyzed for their phonological proximity to the targets. When several responses were given, the last one was chosen for analysis. We applied the following criteria for accuracy: (a) 100% accurate responses (stringent criterion), (b) responses with a maximum of one phoneme deviation from the target (addition, deletion, substitution or wrong position of a phoneme) (liberal criterion), and (c) phonologically cued responses with a maximum of one phoneme deviation from the target (liberal criterion + cueing). In reporting the results, only the stringent criterion is used, unless indicated otherwise. The statistical methods are explained in the Results section.

3. Results

3.1 Experiment I: Novel word learning

Learning outcomes were analyzed with the McNemar test or, in the case of low rates of correct responses, with the binomial test (Siegel & Castellan, 1988). As measured by correct oral naming responses, participant TS with aphasia showed statistically significant learning of the novel picture–word pairs at the start of the third training session (McNemar test, Yates corrected $\chi^2(1, N = 20) = 8.10; p = 0.002$). At one day post-training, TS reached 55% correct (see Fig. 4). Allowing for a one phoneme deviance from the target, her naming accuracy was 80% (liberal criterion). Taking into account also phonologically cued responses and allowing for a one phoneme deviance from the target, her naming accuracy was 95% (liberal criterion + cue). In written naming, her accuracy rates according to stringent, liberal, and liberal + cue criteria were one day post-training 85%, 95% and 100%, respectively.

All of the healthy control participants exhibited statistically significant learning by the start of the second or third training session (i.e. named at least 5 out of 20 items accurately (binomial test, one-tailed, $P(1, N = 20), p = 0.03$). Participant TS's learning rate from training session 1 to the post-training session did not differ statistically from the performance of the weakest healthy control participant (Mann-Whitney test, both stringent and liberal criterion, $U = 13.50, Z = -0.10, p = 0.92$). For the healthy control participants who were only tested for oral naming, the accuracy rates one day post-training varied between 80–100% (stringent criterion) and 95–100% (liberal criterion). Control participant 6 performed at a significantly lower level than the rest of the control group at all other ($t = 6.04$ – 18.56) but the last ($t = 2.33, p = 0.08$) follow-up session (modified t -Test utilizing the Singlims program, Crawford & Garthwaite, 2002, <http://homepages.abdn.ac.uk/j.crawford/pages/dept/SingleCaseMethodsComputerPrograms.HTM>).

Possible effects of word length (in number of phonemes) and phonological neighborhood size (number of real Finnish words that differ from the target novel word with one phoneme) on word learning success were analyzed using chi square tests. For this analysis, the results of all naming probes during the learning and maintenance period were summed up. Word length defined as short (4–6 phonemes; 14 words in the sample) vs. long (7–8 phonemes; 6 words in the sample) did not have a statistically significant effect on participant TS's word

learning or maintenance ($\chi^2(1, N = 160) = 0.76; p = 0.38$). TS showed a tendency to learn and maintain more easily words that had several (5–15) than few (1–3) phonological neighbors; $\chi^2(1, N = 160) = 3.27; p = 0.07$.

3.2 Experiment I: Novel word maintenance

Participant TS's learning was statistically above the initial zero-level up to 4 weeks post-training in oral naming (binomial test, one-tailed, $P(1, N = 20); p = 0.004$) and up to 8 weeks in written naming (binomial test, one-tailed, $P(1, N = 20); p = 0.004$) (see Fig. 4). Applying the liberal + cue criterion, the maintenance was statistically significant throughout the 6-month follow-up both in oral and written naming (for the lowest level in written naming at 6 months post-training, $P(1, N = 20), p = 0.02$). All of the healthy control participants maintained a performance significantly above zero-level up to the end of the follow-up (stringent criterion).

Participant TS's oral and written naming performances were contrasted with the Wilcoxon Matched-Pairs Signed-Ranks test. TS's maintenance of the newly learned words differed according to the testing modality, as she performed better in written than in spoken naming across the follow-up period (Wilcoxon Matched-Pairs Signed-Ranks test; $Z = -3.19; p = 0.001$, all follow-up sessions included). However, at 6 months post-training both written and oral naming had declined to low levels. Similarly to the training phase, there was no statistically significant difference in the maintenance of the training results between participant TS and the weakest-performing healthy control participant (Mann-Whitney test, all follow-up sessions included).

3.3 Summary of the results of Experiment I

Taken together, TS performed at the level of the lowermost end of the control group in short-term novel word learning (one day post-training). During the follow-up, her oral naming declined faster than her written naming.

3.4 Experiment II: The effect of different input and output channel combinations on pseudoword learning

The Kruskal-Wallis test was employed in contrasting the word learning curves in the four different learning conditions. The final naming accuracy (the result of the last naming probe on training day two) was compared across the learning conditions with a chi square test. In the Kruskal-Wallis and chi square analyses, we employed primarily the liberal criterion as TS produced a great number of responses that differed by only one phoneme/grapheme from the target. However, we report also statistics according to the stringent criterion. All four input-output modality combinations promoted novel word learning in participant TS, but her learning rate and the final result varied in the four different learning conditions (Fig. 5). The naming accuracy over the two training sessions differed significantly between the learning conditions (Kruskal-Wallis test liberal criterion $H(3, N = 75) = 9.62, p = 0.02$; Kruskal-Wallis test stringent criterion $H(3, N = 75) = 11.37, p = 0.01$). There was also a statistically significant difference in the final naming accuracy on the second day between the four learning conditions (liberal criterion $\chi^2(3, N = 60) = 27.96; p < 0.001$; stringent criterion, Fisher's exact test, $p < 0.001$). The combination of orthographic input with orthographic

output led to the most accurate naming results during day 1, and finally full acquisition of the novel names during day 2, even according to the stringent criterion.

In further analyses, we focused on the effect of (a) input modality and (b) output modality on learning to name (see Fig. 6 and 7). The results of the two auditory input learning conditions (AUD–WRI + AUD–SPO) were summed across the naming probes, and contrasted with the summative results of the two orthographic input learning conditions (ORT–SPO + ORT–WRI) using the Mann-Whitney test. Orthographic input was found to promote TS's naming performance significantly more than auditory input (stringent and liberal criterion: $U = 2.50$, $Z = 1.98$, $p = 0.048$). The corresponding analysis of the effect of output modality on learning to name did not reveal statistically significant differences according to the liberal criterion ($U = 13.50$, $Z = -0.10$, $p = 0.92$) while it did according to the stringent criterion ($U = 2.50$, $Z = 1.98$, $p < 0.048$). Chi square analyses of only the final naming probe of day two (D2 N3) showed similar results: Orthographic input led to better learning than auditory input (liberal criterion: $\chi^2 = 21.60$, $p < 0.001$; stringent criterion = 11.09 , $p < 0.001$) The effect of output modality on learning did not reach statistical significance by the liberal criterion ($\chi^2 = 2.40$, $p = 0.12$) but did reach significance by the stringent criterion ($\chi^2 = 19.72$, $p < 0.001$).

4. Discussion

The present case study set out to examine the ability of our participant TS, an individual with chronic aphasia and anomia, to learn novel word–referent pairs in different input/output modalities. The results indicated that she learned and maintained novel vocabulary better in the written than the spoken domain. Further short-term word learning tasks that systematically manipulated input/output modalities confirmed that orthographic input resulted in the best learning outcomes, and that the combination of orthographic input and output yielded most accurate final acquisition of the novel words.

4.1 TS and earlier evidence on novel word learning in aphasia

There is accumulating evidence showing that some aphasic individuals retain their capacity to acquire novel linguistic contents (Grossman & Carey, 1987; Gupta et al., 2006; McGrane, 2006; Tuomiranta et al., 2011, 2012, 2014). Nevertheless, this capacity is often quite limited. The learning outcomes of TS, for example, are only surpassed by the case AA who learned novel words on par with healthy controls in an experiment using the same learning paradigm as in Experiment 1 of the present study (Tuomiranta et al., 2014). Also TS showed a high level of learning of 20 novel words with this setup. Learning was measured by a demanding criterion, i.e. fully accurate spontaneous naming and yet, TS's naming accuracy during the training phase did not differ significantly from the weakest performing healthy control participant.

Besides short-term acquisition, it is important to probe long-term maintenance of novel vocabulary as it reflects the functionality of the second major phase of the CLS model, shift from the buildup of hippocampal word–referent associations to cortical long-term storage (see O'Reilly & Norman, 2002), which is the ultimate goal of word learning. However, long-term maintenance of newly acquired words has only been investigated in few studies

with aphasic individuals. This ability has varied considerably from fast deterioration (e.g. Tuomiranta et al., 2011) up to maintenance levels on par with healthy controls (case AA of Tuomiranta et al., 2014). TS's spontaneous, fully accurate naming result declined to non-significant levels at 8 weeks post-training for spoken naming and at 6 months post-training for written naming. However, when a liberal criterion (approving of one-phoneme deviation from the target and including responses given to a syllable cue) was applied to TS's responses, she showed statistically significant maintenance throughout the follow-up period.

As regards the superiority of TS's written to oral naming performance during the long-term follow-up, earlier studies provide limited material for comparison. McGrane (2006) measured learning with both oral and written naming but several details of the study design make it difficult to compare the learning results to those in the present investigation. For example, McGrane's (2006) study included individually tailored learning methods and training time. Additionally, only five targets were trained in each session, scoring criteria were less stringent, and only one follow-up (up to five days post-training) was administered. Of McGrane's (2006) participants, five out of twelve seemed to perform better in written than spoken naming of the novel items, one showed the opposite pattern and six seemed equally strong in both modalities, though this may have been due to a ceiling or floor effect in some cases.

4.2 Superiority of the orthographic domain in word learning

TS's more successful learning following only orthographic vs. only phonological input is in line with findings from healthy adults (Dean, Yekovich, & Gray, 1988; Gallo, McDermott, Percer, & Roediger, 2001; Nelson, Balass, & Perfetti, 2005). Nelson et al. (2005) suggest that this effect arises from dual coding of orthographic input, leading to stronger memory for these words through more extensive activation of the language network and more numerous episodic traces. A written input would thus be simultaneously processed through both orthographic and phonological routes, while phonological input would not be automatically converted into orthography. In a study by Basso et al. (2001), healthy participants learned pseudoword–real object pairs with three different methods: oral repetition, reading aloud and orthographic cueing. The best learning outcome followed orthographic cueing, which was suggested to originate from the higher effort / self-production requirement of this method.

One remarkable feature of the present case, TS, is that her language profile was inconsistent with her stronger vocabulary learning and maintenance in the orthographic than in the phonological modality. TS could namely repeat words and pseudowords better than she could read them aloud, which also applies to the production accuracy during the initial training trials of Experiment II². On the basis of the present data, it is difficult to draw definitive conclusions for the reasons underlying these contradictory findings. Incremental associative word learning tasks administered over more than one day set quite different cognitive demands as compared to “one-shot” word reading and repetition tasks. The former

²TS's production accuracy was significantly better in the AUD–SPO than the ORT–SPO learning condition of Experiment II. The comparison was made of the first training round of the first training session (Mann-Whitney test: $U = 167.50$, $Z = -2.26$, $p = 0.02$) and of the first training round of the second training session ($U = 171.00$, $Z = -2.41$, $p = 0.02$).

ones require functional cortical-hippocampal interaction (O'Reilly & Norman, 2002) whereas the latter ones presumably hinge upon cortical systems only (for a review, see Price, 2012). Better repetition in comparison to reading aloud could be attributed to the temporary priming of the auditory model during the repetition task. However, this temporary priming may not allow for lasting learning effects. Thus the integrity of hippocampal connections from the orthographic vs. phonological input systems that can be differentially affected might play a role here. Moreover, it could be that the potential benefit of dual coding of orthographic input present in healthy learners (cf. Nelson et al., 2005) emerges in aphasia only during a longer learning task.

There is some evidence that TS's spoken output suffered from interference among the phonological representations active in short-term memory. In the learning probe tests of conditions (Experiment II; Fig. 5, 6, and 7) that employed spoken output, TS tended to produce naming attempts that blended phonological features of stimulus names. However, the naming accuracy of the items produced orally improved from the last probe test of the first session to the start of the second session. This may indicate that phonological interference cleared up during the interval between the sessions (see also Martin, Fink, Laine, & Ayala, 2004).

Earlier case studies of aphasic participants have evidenced differential patterns and degrees of impairment in phonological vs. orthographic output lexicons (Bub & Kertesz, 1982; Hillis, Rapp, & Caramazza, 1999; Nickels, 2002; Rapp, Benzing, & Caramazza, 1997; Shelton & Weinrich, 1997; Wambaugh & Wright, 2007). Spelling may generally be a highly vulnerable linguistic function after brain damage but in some aphasia cases, writing is more accurate than spoken production (e.g. Bowes & Martin, 2006; Bub & Kertesz, 1982; Nickels, 1992; Shelton & Weinrich, 1997). These case studies have supported the orthographic autonomy hypothesis (Damian, Dorjee, & Stadthagen-Gonzalez, 2011; Rapp et al., 1997). According to this hypothesis, writing is possible without access to phonology. As TS's phonological processing was vulnerable to interference, the possibility of bypassing phonological processing by using orthographic processes might have been the key to faster novel word learning for TS.

Several lines of evidence point to TS's strength in the written language domain. Her visuo-spatial serial memory was more efficient than the auditory one, and her self-report on what she did in order to memorize the word forms points to effective association techniques. TS actively searched for an existing real word that (phonologically and orthographically; Finnish is an orthographically fully transparent language) resembled the novel one and then associated the two. In order to retrieve the newly learned word forms, TS seemed to rely on the orthographic form also during spoken production. She visualized the letters of the word, and if a computer keyboard was at sight, she looked at the keys. Due to this observation, the keyboard was covered during the learning experiments of Experiment II.

Results from earlier studies have pointed to a correlation between successful novel word acquisition and auditory digit span length as well as pseudoword repetition accuracy (e.g. Gupta, 2003; Gupta et al., 2006). TS and our previously presented case AA (Tuomiranta et al., 2014) show that novel words can be learned successfully even when pseudoword

repetition skills are impaired and auditory spans very limited (see also case LT in Kohen et al., 2012). Interestingly, these abilities were poorer in AA who nevertheless showed the best novel word learning. It is likely that functional orthographic processing helped TS and AA to bypass the impairments of phonological processing in learning novel words.

Participant TS did not reach quite as high and lasting novel word learning outcomes as AA (Tuomiranta et al., 2014). The cognitive-linguistic profiles of these cases show some similarities but differ with respect to auditory comprehension (clearly more compromised in AA). There is some dissociation between these two cases in their ability to repeat (TS > AA) and to read aloud (TS < AA) words and pseudowords. Interestingly, both AA and TS had suffered extensive left-hemispheric lesions and their aphasic symptoms were classified as global several weeks post-onset. While AA had a left temporal lesion that spared medial temporal structures including the hippocampal areas, TS's lesion encompassed also parts of the parietal and frontal cortex as well as the left hippocampus. Following the CLS model for learning (O'Reilly & Norman, 2002), the status of the hippocampal structures (lesioned in TS) and the extent of the left cortical lesion (more extensive in TS) might explain the behavioral differences between these two persons with aphasia. The hippocampal structures have been connected to the initial binding process during which the novel entities are associated together with temporary, episodic traces. The left posterior temporal lobe and the inferior frontal lobe (both lesioned in TS) have been suggested to play an important role in long-term maintenance of novel vocabulary (Hultén, Laaksonen, Vihla, Laine, & Salmelin, 2010).

4.3 Methodological considerations of the present study

While the experimental design was initially planned as a direct replication of the one used in three previous studies (Tuomiranta et al., 2011; 2012, 2014), the addition of the written naming task to each follow-up test makes the present experiment design somewhat different and therefore not fully comparable to the previous studies. TS was administered double follow-up naming tests (oral and written naming) which naturally enough resulted in a higher number of accesses to the novel word forms. Consequently, this might have given her extra training, and as a result, an advantage in maintaining the novel words.

It is important to note that frequent probing of learning outcomes could have promoted the consolidation and maintenance of novel words especially in Experiment I. Experiment II with modality-specific learning experiments was for practical reasons limited to short-term learning. It would be of theoretical and clinical interest to also look at the long-term maintenance of novel words learned through different modality combinations.

The learning performance of control participant 6 differed from the rest of the control group. In two studies by Hultén, Vihla, Laine, & Salmelin, 2009; Hultén et al., 2010) great inter-individual differences were found among young healthy participants in learning and maintaining the same kind of novel word-novel referent pairs as in the present study. Also in our first study with a similar core experiment as in the present one (Tuomiranta et al., 2011), the two matched healthy control participants performed at very different levels when compared to each other. We thus assumed that the control participant that performed at the lowest level in the present study merely showed the normal variation rather than being

impaired in learning. The short cognitive-linguistic background assessment and the interview of this particular control participant did not reveal anything that would point at a possible impairment in learning or language functions.

4.4 Implications for anomia treatment

A comparison of test results and novel word learning outcomes showed that TS could repeat words and pseudowords better than she read them aloud. However, in learning new words, orthographic input led to better success than phonological input. The case suggests that broad conclusions on learning capacity should not be drawn from restricted test results, and encourages the use of short-term learning experiments on novel material to identify functioning channels for lexical acquisition. In our earlier case study of AA (Tuomiranta et al., 2014), novel word learning capacity translated successfully into therapy where AA re-learned familiar but lost words. TS's ability to re-learn familiar words has not been probed, and it remains to be seen whether it would exhibit the same modality-specific effects as her acquisition of novel words, as was the case with AA.

While the present study focused on learning modes and not cueing, it is worth noting that phonological and orthographic cues are regularly and successfully used in the treatment of persons with aphasia. These two modalities are often used in combination, and their effects are not measured separately. Theoretically, it is possible that for some individuals using a simple procedure instead of a multimodal task (for instance including only orthographic input/ output that was particularly effective for the present case TS as well as an earlier case AA) could lead to less interference, and consequently, faster and stronger learning effects. Further research should shed light on this question, too.

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References

- Academy of Neurologic Communication Disorders and Sciences Aphasia Treatment Website. Aphasia treatment evidence tables (n.d.). Retrieved March 13, 2014 from <http://aphasiatx.arizona.edu>
- Basso, A. Aphasia and its therapy. New York, USA: Oxford University Press; 2003.
- Basso A, Marangolo P, Piras F, Galluzzi C. Acquisition of new "words" in normal subjects: A suggestion for the treatment of anomia. *Brain and Language*. 2001; 77:45–59. [PubMed: 11247655]
- Best W, Herbert R, Hickin J, Osborne F, Howard D. Phonological and orthographic facilitation of word-retrieval in aphasia: Immediate and delayed effects. *Aphasiology*. 2002; 16:151–168.
- Bowes K, Martin N. Dissociated written and oral naming: A case study. *Brain and Language*. 2006; 99:32–33.
- Breitenstein C, Kamping S, Jansen A, Schomacher M, Knecht S. Word learning can be achieved without feedback: Implications to aphasia therapy. *Restorative Neurology and Neuroscience*. 2004; 22:445–458. [PubMed: 15798363]
- Bruce C, Howard D. Why don't Broca's aphasics cue themselves? An investigation of phonemic cueing and tip of the tongue information. *Neuropsychologia*. 1988; 26:253–264. [PubMed: 3041308]

- Bub D, Kertesz A. Evidence for lexicographic processing in a patient with preserved written over oral single word naming. *Brain*. 1982; 105:697–717. [PubMed: 7139251]
- Crawford JR, Garthwaite PH. Investigation of the single case in neuropsychology: Confidence limits on the abnormality of test scores and test score differences. *Neuropsychologia*. 2002; 40:1196–1208. [PubMed: 11931923]
- Damian MF, Dorjee D, Stadthagen-Gonzalez H. Long-term repetition priming in spoken and written word production: Evidence for a contribution of phonology to handwriting. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 2011; 37:813–826.
- Dean RS, Yekovich FR, Gray JW. The effect of modality on long-term recognition memory. *Contemporary Educational Psychology*. 1988; 13:102–115.
- De Renzi E, Faglioni P. Normative data and screening power of a shortened version of the Token Test. *Cortex*. 1978; 14:41–49. [PubMed: 16295108]
- De Renzi E, Nichelli P. Verbal and non-verbal short-term memory impairment following hemispheric damage. *Cortex*. 1975; 11:341–354. [PubMed: 1222578]
- Gallo DA, McDermott KB, Percer J, Roediger HL. Modality effects in false recall and false recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 2001; 27:339–353.
- Goldrick M, Rapp B. Lexical and post-lexical phonological representations in spoken production. *Cognition*. 2007; 102:219–260. [PubMed: 16483561]
- Grönholm P, Rinne JO, Vorobyev V, Laine M. Naming of newly learned objects: a PET activation study. *Cognitive Brain Research*. 2005; 25:359–371. [PubMed: 16095887]
- Grossman M, Carey S. Selective word-learning deficits in aphasia. *Brain and Language*. 1987; 32:306–324. [PubMed: 2446700]
- Gupta P. Examining the relationship between word learning, nonword repetition, and immediate serial recall in adults. *The Quarterly Journal of Experimental Psychology*. 2003; 54:1213–1236. [PubMed: 12959911]
- Gupta P, Martin N, Abbs B, Schwartz M, Lipinski J. New word learning in aphasic patients: Dissociating phonological and semantic components. *Brain and Language*. 2006; 99:8–9.
- Hillis AE, Rapp B, Caramazza A. When a rose is a rose in speech but tulip in writing. *Cortex*. 1999; 35:337–356. [PubMed: 10440073]
- Howard D, Harding D. Self-cueing of word retrieval by a woman with aphasia: why a letter board works. *Aphasiology*. 1998; 12:399–420.
- Hultén A, Laaksonen H, Vihla M, Laine M, Salmelin R. Modulation of brain activation after learning predicts long-term memory for words. *The Journal of Neuroscience*. 2010; 30:15160–15164. [PubMed: 21068321]
- Hultén A, Vihla M, Laine M, Salmelin R. Accessing newly learned names and meanings in the native language. *Human Brain Mapping*. 2009; 30:976–989. [PubMed: 18412130]
- Kelly H, Armstrong L. New word learning in people with aphasia. *Aphasiology*. 2009; 23:1398–1417.
- Kohen F, Sola C, Tuomiranta L, Laine M, Martin N. Preservation of novel word learning through orthographic but not auditory input in conduction aphasia: A replication of Tuomiranta, Rautakoski, Martin & Laine (2011). *Procedia - Social and Behavioral Sciences*. 2012; 61:110–111.
- Laganaro M, Di Pietro M, Schnider A. What does recovery from anomia tell us about the underlying impairment: The case of similar anomic patterns and different recovery. *Neuropsychologia*. 2006; 44:534–545. [PubMed: 16112147]
- Laine, M.; Koivuselkä-Sallinen, P.; Hänninen, R.; Niemi, J. *Bostonin Nimentätesti* [The Finnish version of the Boston Naming Test]. Helsinki: Psykologien Kustannus; 1997a.
- Laine M, Kujala P, Niemi J, Uusipaikka E. On the nature of naming difficulties in aphasia. *Cortex*. 1992; 28:537–554. [PubMed: 1282448]
- Laine, M.; Martin, N. *Anomia: Theoretical and Clinical Aspects*. Hove, UK: Psychology Press; 2006.
- Laine, M.; Niemi, J.; Koivuselkä-Sallinen, P.; Tuomainen, J. *Bostonin Diagnostinen Afasiatutkimus* [The standardized Finnish version of the Boston Diagnostic Aphasia Examination]. Helsinki: Psykologien Kustannus; 1997b.

- Laine M, Salmelin R. Neurocognition of new word learning in the native tongue: lessons from the Ancient Farming Equipment paradigm. *Language Learning*. 2010; 60(Suppl. 2):25–44.
- Lorenz A, Nickels L. Orthographic cueing in aphasia: How does it work? *Aphasiology*. 2007; 21:670–686.
- Martin N, Fink R, Laine M, Ayala J. Immediate and short-term effects of contextual priming on word retrieval in aphasia. *Aphasiology*. 2004; 18:867–898.
- Martin, N.; Kohen, FP.; Kalinyak-Fliszar, M. A processing approach to the assessment of language and verbal short-term memory abilities in aphasia; Charleston, SC. Clinical Aphasiology Conference; 2010 May 23 – 27.
- McGrane, H. An investigation into the ability of adults with post-stroke aphasia to learn new vocabulary. PhD thesis; 2006. <http://www.qmu.ac.uk/ssrc/pubs/McGrane2006PhD.pdf>
- Nelson JR, Balass M, Perfetti CA. Differences between written and spoken input in learning words. *Written Language & Literacy*. 2005; 8:25–44.
- Nickels LA. The autocue? Self-generated phonemic cues in the treatment of a disorder of reading and naming. *Cognitive Neuropsychology*. 1992; 9:155–182.
- Nickels L. Therapy for naming disorders: revisiting, revising, and reviewing. *Aphasiology*. 2002; 16:936–979.
- O'Reilly RC, Norman KA. Hippocampal and neocortical contributions to memory: advances in the complementary learning systems framework. *Trends in Cognitive Sciences*. 2002; 6:505–510. [PubMed: 12475710]
- Poutiainen, E.; Kalska, H.; Laasonen, M.; Närhi, V.; Räsänen, P. TMT Trail making –testi. Helsinki: Psykologien Kustannus; 2010.
- Price CJ. A review and synthesis of the first 20 years of PET and fMRI studies of heard speech, spoken language and reading. *NeuroImage*. 2012; 62:816–847. [PubMed: 22584224]
- Rapp B, Benzing L, Caramazza A. The autonomy of lexical orthography. *Cognitive Neuropsychology*. 1997; 14:71–104.
- Renvall K, Laine M, Laakso M, Martin N. Anomia treatment with contextual priming: A case study. *Aphasiology*. 2003; 17:305–328.
- Shelton JR, Weinrich M. Further evidence of a dissociation between output phonological and orthographic lexicons: A case study. *Cognitive Neuropsychology*. 1997; 14:105–129.
- Siegel, S.; Castellan, NJ. Nonparametric statistics for the behavioral sciences. 2nd ed.. Singapore: McGraw Hill Book Co; 1988.
- Tuomiranta LM, Càmara E, Froudish Walsh S, Ripolles P, Saunavaara JP, Parkkola R, Martin N, Rodríguez-Fornells A, Laine M. Hidden word learning capacity through orthography in aphasia. *Cortex*. 2014; 50:174–191. [PubMed: 24262200]
- Tuomiranta L, Grönholm-Nyman P, Kohen F, Rautakoski P, Laine M, Martin N. Learning and maintaining new vocabulary in persons with aphasia: Two controlled case studies. *Aphasiology*. 2011; 25:1030–1052.
- Tuomiranta, L.; Laine, M.; Martin, N. Adaptation of the Temple Assessment of Language and Short-term Memory In Aphasia (TALSA) into the Finnish Language. Turku: Department of Psychology and Logopedics, Åbo Akademi University; 2009. unpublished
- Tuomiranta L, Rautakoski P, Rinne JO, Martin N, Laine M. Long-term maintenance of novel vocabulary in persons with chronic aphasia. *Aphasiology*. 2012; 26:1053–1073.
- Wambaugh JL, Wright S. Improved effects of word-retrieval treatments subsequent to addition of the orthographic form. *Aphasiology*. 2007; 21:632–642.
- Whitworth, A.; Webster, J.; Howard, D. A cognitive neuropsychological approach to assessment and intervention in aphasia. A clinicians guide. Hove: Psychology Press; 2005.

HIGHLIGHTS

- an aphasic individual TS learned novel words on par with healthy participants
- in the long-term, TS maintained better written than spoken forms of novel words
- written input resulted in better novel word learning than spoken input
- TS's written/spoken test profile was opposite to the corresponding learning profile
- word learning channels can be differentially affected in aphasia

A

KAHA

B

ULKKA

Figure 1.
Sample items of Experiment 1 (A) and Experiment 2 (B).

Figure 2.
Axial T2-weighted MRI of participant TS's brain 6 days post-onset.

A

B

Figure 3.
The setups of Experiment I (A) and Experiment II (B).

Figure 4. Spontaneous confrontation naming results in Experiment I as percentage of accurate responses (stringent criterion). TS's performance during the follow-up is depicted separately for oral (oral) and written (wri) naming. The control (ctrl) participants named only orally. tr, training session.

Figure 5. Pseudoword learning of participant TS in Experiment II as number of correct responses during spontaneous confrontation naming probe tests (N)(liberal criterion, one phoneme distortion allowed). Four different learning conditions were administered, each one in two sessions on two consecutive days (D). D1-N1, the naming probe test administered after the second training round of the first training session; D1-N2, the naming probe test administered after the final fourth training round of the first training session; D2-N1, the naming probe test administered prior to any training during the second training session; D2-N2, the naming probe test administered after the second training round of the second training session; D2-N3, the naming probe test administered after the final fourth training round of the second training session.

Figure 6. Pseudoword learning of participant TS in Experiment II as a function of input modality during learning. Learning is presented as number of correct responses during spontaneous confrontation naming (N) (liberal criterion, one phoneme distortion allowed). Four different learning conditions were administered, each one in two sessions on two consecutive days (D). The effects of ORT–SPO and ORT–WRI conditions are summed to visualize the effect of orthographic (ORT) input and the effects of AUD–SPO and AUD–WRI conditions to show the effect of auditory (AUD) input.

Figure 7.

Pseudoword learning of participant TS in Experiment II as a function of output modality during learning. Learning is presented as number of correct responses during spontaneous confrontation naming (N) (liberal criterion, one phoneme distortion allowed). Four different learning conditions were administered, each one in two sessions on two consecutive days (D). The effects of AUD-WRI and ORT-WRI conditions are summed to visualize the effect of written (WRI) output and the effects of AUD-SPO and ORT-SPO conditions to show the effect of spoken (SPO) output.

Table 1

Participant TS's scores on the standardized Finnish version of the Boston Diagnostic Aphasia Examination (Laine et al. 1997b) at the start of the learning experiments. Performances lower than the 50th percentile are presented in bold.

Task	TS
<u>Severity rating</u>	3
<u>Fluency</u>	
Articulation rating	3 /7
Phrase length	5 /7
Melodic line	5 /7
Verbal agility	7/14
<u>Auditory comprehension</u>	
Word discrimination	68/72
Body-part identification	19.5/20
Commands	15/15
Complex ideational material	8/12
<u>Naming</u>	
Responsive naming	24/30
Confrontation naming	87/114
Animal naming	13
<u>Oral reading</u>	
Word reading	25/30
Sentence reading	7/10
<u>Repetition</u>	
Repetition of words	8/10
Repetition of high-probability sentences	2/8
Repetition of low-probability sentences	1/8
<u>Reading comprehension</u>	
Word recognition	7/8
Comprehension of spelling	2/8
Word-picture matching	9/10
Reading sentences and paragraphs	6/10
<u>Writing</u>	
Simple dictation	14/15
Writing to dictation	7/10
Written naming	7/10
Narrative writing	2/5
Sentences to dictation	6/12

Table 2

TS's performance on various background tests.

Task	TS's result
<u>Language comprehension</u>	
Token test (auditorily)	27 / 36
Token test (in reading)	30 / 36
<u>Lexical-semantics</u>	
50-picture classification task ^a	48 / 50
Semantic odd-one-out task ^b	
pictures	15 / 20
words	17 / 20
<u>Production varied for frequency & length</u>	
Repetition of 90 words	80 / 90 ^{*Freq}
Repetition of 90 pseudowords	66 / 90 ^{*Length}
Reading aloud 90 words	61 / 90 ^{*Freq}
Reading aloud 90 pseudowords	12 / 90
<u>Spans (all forward and in serial order)</u>	
Digits (pointing)	3
(oral repetition)	4
Words (oral repetition)	3
Pseudowords (oral repetition)	1
Corsi Block Tapping-Task (pointing)	5
<u>Other</u>	
TMT/ TM-A (percentile)	70

The proportions in bold are out of the range of preliminary normative data (Laine et al. 1992^a, Renvall et al. 2003^b) of neurologically intact older adults (age 50–70 years, $n = 5$; age 61–79 years, $n = 4–5$).

* statistically significant effect of word/pseudoword length or word frequency (freq).