Introduction

We report the results of a computer-based theory-driven remediation program for distinct disorders of phonological decoding and encoding in aphasia. On the basis of the serial model of speech production from Levelt, Roelofs and Meyer (1999), three levels of expressive word form processing can be distinguished: lexical activation (word form retrieval), post-lexical phonological encoding (selection and/or sequencing of phonemes) and phonetic encoding (programming of speech motor plans).

Considering phonological decoding, several approaches explaining the underlying processes were developed in recent years (e.g. cohort model of Marslen-Wilson, Moss, & van Halen, 1996; interactive TRACE model of McClelland & Elman, 1986; SHORTLIST-model of Norris, 1994). These models have in common that they map acoustic information onto lexical information. First, acoustic-phonetic decoding takes place, i.e. temporal and spectral analysis of the speech signal. Subsequently, the information is transformed into a pre-lexical representation. As a final step in lexical decoding, the corresponding word form is activated (cf. Cutler & Clifton, 1999).

In aphasia, impairments of phonological decoding and encoding very frequently appear in an associated way (Martin & Saffran, 2002). Nevertheless, dissociated impairments may be found within decoding and encoding. Differential breakdown on the three levels of encoding (lexical, post-lexical and phonetic) is clinically usually attributed to Wernicke's aphasia, conduction aphasia and apraxia of speech (e.g. Kohn, 1993). With respect to decoding, access to phonological, lexical and semantic information may be specifically affected which was called word-sound, word-form and word-meaning deafness (c.f. Franklin, 1989). Additional impairments in pre-lexical phonological processing can be assumed.

Differential impacts of therapy can be expected when the training aims specifically at the underlying deficit. In our approach, we target at the different processing stages by different material parameters. We predict greatest benefit in treatment when material is used which is most demanding with respect to the disorder. In other words, a strictly deficit-oriented treatment approach is applied.

For one patient with conduction aphasia and two patients with apraxia of speech, we were able to demonstrate the efficiency of this deficit-oriented approach for relatively pure phonological encoding impairments (Corsten, Mende, Cholewa, & Huber, 2005; Mende, Corsten, Bung, Cholewa, Willmes, & Huber, under review).

Here we present a patient with a combined input and output impairment. The training material was varied across four linguistic parameters: lexicality (words versus pseudowords), contrast position (onset versus coda), phonetic complexity (increasing sonority) as well as phonological similarity (similar versus non-similar words). Patient PS who showed disorders on pre- and post-lexical phonological levels of processing should benefit most from processing pseudowords with minimal contrasts in coda position because this material should require most extensive pre- and post-lexical segmentation and sequencing of phonological segments.

Methods

Patient PS

Patients of our aphasia ward were consecutively examined and screened for impairment of phonological and phonetic word form encoding by using the Aachen Aphasia Test (AAT, Huber, Poeck, Weniger, & Willmes, 1983) and additional screening tests.

Patient PS, a 52 years old man, suffered a left-hemisphere CVA in the temporo-parietal region. He showed a moderate conduction aphasia 11 months post onset. The spontaneous speech was fluent with severe word finding difficulties and many phonemic paraphasias. He exhibited ‘conduite d’approche’ very frequently. There were no signs of dysarthria or speech apraxia. PS had a digit span of 3. Additionally, he showed an outstanding input impairment with great difficulties in phonologically based identification tasks.

Material

Treatment took place by using a minimal phonemic contrast practice. The training material consisted of monosyllabic words that were systematically controlled for lexicality (real word versus pseudoword), position of the minimal phonemic contrast (onset versus coda), and phonetic complexity (increasing versus equal sonority). As a control condition, the material also included words without any phonemic and semantic similarity (in total 1152 items).

Procedure

The impact of these factors was studied in an alternating-treatments design employing control tests to assess baseline, outcome, and stability effects. Treatment lasted for six weeks during which therapy took place twice a day with each session lasting 60 minutes (overall 48 sessions). Each of the 6 different conditions was practiced in 16 sessions.

All exercises were computer-assisted. One session consisted of three main tasks: discrimination, identification, and reproduction.

During *Discrimination*, which served as warming-up, the patients were asked to judge two auditorily presented items to be equal or different. At the beginning of the following tasks, the full set of the four practice items was presented in oral as well as well as in written form. The task *Identification* consisted of four steps: The patients were asked to identify one auditorily presented item out of four items at the screen. Then they should point to sequences of two, three and four auditorily presented items on the screen in the given order. During *Reproduction*, the training proceeded also in four steps: Oral reproduction of one item, of item pairs and of sequences of three and four items.

Expectations

For patients with pre- and postlexical phonological impairments, we expected an improvement from processing items contrasted in coda position as it requires a full segmentation opposed to onset contrasts. In addition, pseudowords should result in specific improvement as they focus on pre- and post-lexical processing respectively. For the control condition, no effect was assumed.

Results

As predicted, patient PS showed improvement when practising items contrasted in the coda position. Especially, he showed enhancements in decoding pseudowords with such contrasts. During reproduction, PS benefited from training with words contrasted in coda position (see table 1).

Control tests that were applied before, during and after training demonstrated improved phonological performance on repetition of words and pseudowords (Page rank test, $p < .05$). These gains remained stable over a 3-months period of no treatment. In the decoding tests, i.e discrimination of pseudowords, rhyme judgement of words and of pseudowords, no improvements were found because of ceiling effects. In identification of pseudowords, where the patient has a profound disorder, surprisingly no effect was found.

Table 1 Trend analysis data for patient PS (p-values for polynomial trends within the ANOVA framework; bold: significant p-values according to the adjustment for multiple testing, Bonferroni correction)

Task	*Words*	*Words onset*	*Pseudow. onset*	*Words coda*	*Pseudow. Coda*	*Increasing sonority*
Identification of 1 item	$p = .173$	$p = .346$	$p = .132$	$p = .029$	$p = .078$	$p = .317$
Identification of 2 items	$p = .448$	$p = .458$	$p = .437$	$p = .052$	**$p = .004$**	$p = .093$
Identification of 3 items	$p = .155$	$p = .310$	$p = .416$	$p = .031$	**$p = .006$**	$p = .261$
Identification of 4 items	$p = .265$	$p = .348$	$p = .254$	$p = .027$	**$p = .006$**	$p = .171$
Reproduction of 1 item	$p = .128$	$p = .132$	$p = .167$	$p = .315$	$p = .133$	$p = .187$
Reproduction of 2 items	$p = .358$	$p = .415$	$p = .168$	$p = .459$	$p = .163$	$p = .480$
Reproduction of 3 items	$p = .131$	$p = .386$	$p = .019$	**$p = .003$**	$p = .298$	$p = .448$
Reproduction of 4 items	$p = .014$	$p = .376$	$p = .168$	$p = .205$	$p = .140$	$p = .118$

Conclusion

In accordance with the theory of various levels of phonological de- and encoding, we found differential effects of treatment material. Only the treatment conditions with contrast in coda position led to improvement. As expected, PS showed positive linear trends in the identification tasks for pseudowords contrasted in coda. The encoding performance was enhanced by the reproduction of words with coda contrasts. Therefore, the theoretical claim that pseudowords with coda contrasts would be most effective in the case of a pre-lexical phonological decoding impairment could be confirmed. In post-lexical phonological encoding, coda contrasts stimulated improvements as well. Coda contrasts should focus on full selection and/or sequencing of phonological segments.

As expected, PS improved in phonological encoding in post treatment performance measured by our control tests. This was in accordance with his therapy gains. This improvement remained stable. However, the patient’s performance of input processing (identification of pseudowords) in the control tests did not change. This might be due to the right/false judgement which might be not fine-grained enough. Post-hoc qualitative error analysis showed indeed a decrease of uncertainties and of questions for repeat.

To summarise, the results demonstrate that our material-based implicit treatment approach is promising for the treatment of pre-lexical and post-lexical phonological processing impairments. The study highlights that treatment should be impairment-specific and based on corresponding linguistic demands of the practice material. Further applications of this treatment approach are necessary.

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