Auditory repetition of words and pseudowords: an fMRI study

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Introduction

Cognitive processes which are known to be relevant for overt word and pseudoword repetition are phonetic and phonological de- and encoding (cf. Indefrey & Levelt, 2004). In contrast to real words, unfamiliar phoneme sequences (pseudowords) neither have a lexical entry nor a semantic content. Thus, repetition of real words may be processed via a lexical route which contains access to lexical entries and semantic concepts, as well as via a nonlexical route which is based on acoustic-phonemic conversion (cf. Hanley et al., 2004; Fig. 1), but pseudoword repetition should exclusively rely on the nonlexical route. The question is still unresolved whether semantic processing of lexical concepts is required for word repetition compared to pseudoword repetition.

The roles of semantic processing and cognitive routes in word and pseudoword repetition may be elucidated by analyses of their neural correlates. Therefore, we intended to examine neural regions specific to word and pseudoword repetition. By contrasting word with pseudoword repetition, we can reveal brain areas specific to word repetition, e. g. areas responsible for semantic processing. On the contrary, pseudoword repetition should reveal the impact of the missing lexical entry and the unfamiliarity of the phoneme sequence on cognitive processing.

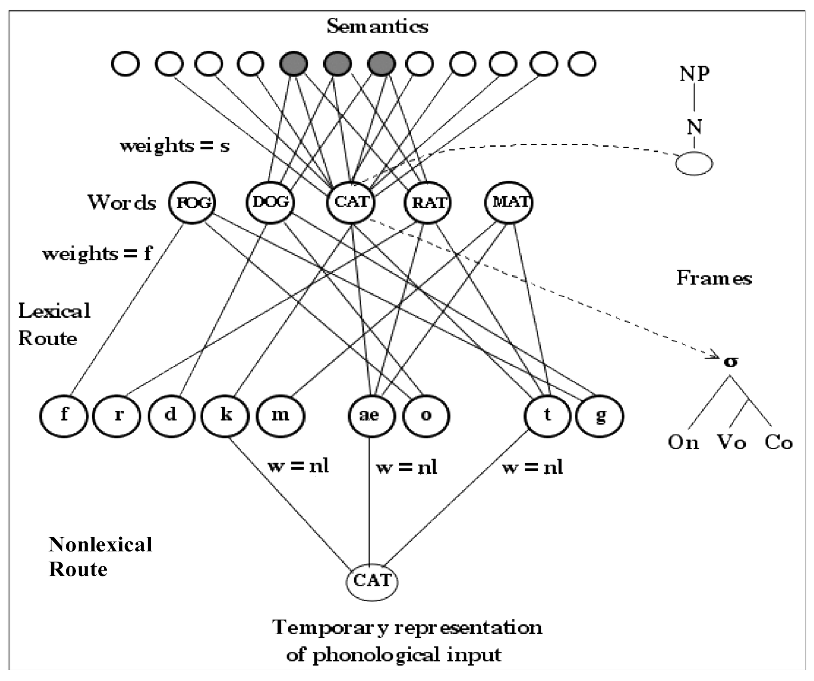

Fig. 1: A dual-route model of repetition (Hanley et al., 2004).

	CVCV	CCVCV	CVCVCV	CCVCVCV
Real words	20	10	20	10
Pseudowords	20	10	20	10
	<fo-to>	<blu-me>	<ge-mü-se>	<pra-li-ne>
	<ru-ga>	<klie-he>	<ra-ge-lie>	<frei-me-lei>

Fig. 2: Stimuli for repetition (C = consonant, V = vowel).

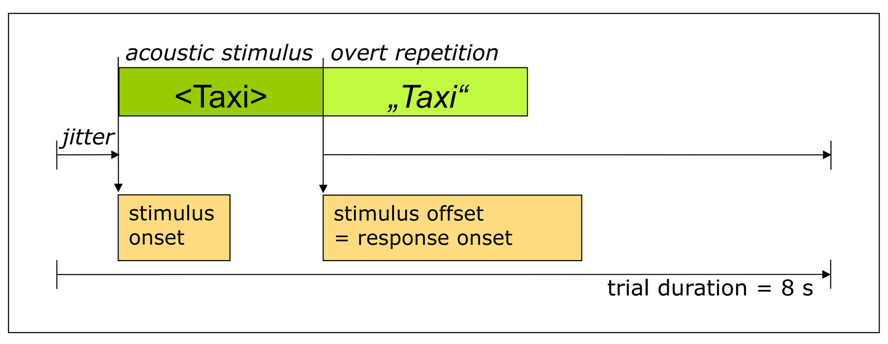

Fig. 3: Experimental design.

Methods

34 native German speakers (18m/16f), with a median age of 27.5 years (range 18-69) without any neurological or hearing deficit, participated in the study.
19 subjects were right-handed and 15 left-handed.

During scanning in a Siemens 3 Tesla MR scanner 60 words and 60 di- and trisyllabic pseudowords (cf. Fig. 2) were presented via headphones, and subjects were instructed to overtly repeat them. The stimuli were balanced for length, syllable structure, stress and frequency of the stressed syllable; real words were also balanced for word frequency, imageability and semantic field. An event-related design with two sessions was used with a trial duration of 8 s. – Fig. 3 shows the experimental design.

T1-weighted anatomical images were acquired using MP-RAGE with 160 sagittal slices, 1 mm thickness, no gap, TR/TE of 2200 ms/2.15 ms, flip angle of 12° and a matrix size of 256 x 256. Echoplanar images were acquired with 30 axial slices, 3 mm thickness, no gap, TR/TE of 1600 ms/30 ms, flip angle of 70° and a matrix size of 192 x 192.

Using SPM5 (http://www.fil.ion.ucl.ac.uk/spm/), stimulus offset was modelled as response onset in the GLM (cf. Fig. 3). One-sample t-tests were performed for the main effects (words > rest, pseudowords > rest), flexible-factorial ANOVAs for the specific effects (pseudowords > words, words > pseudowords) and a two-sample t-test for handedness (left-handed > right-handed).

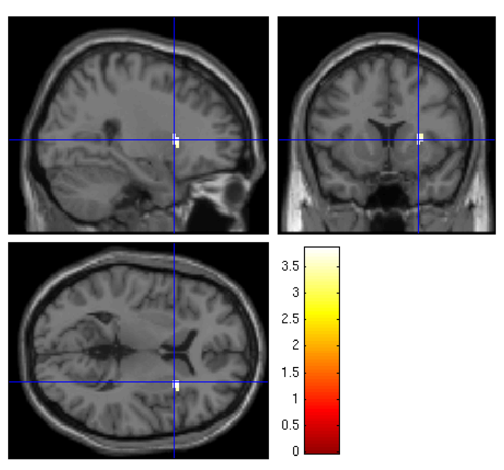
Fig. 4: Functional activation maps laid over average MP-RAGE of all subjects: left-handed > right-handed subjects; .001 (unc.), T = 3.37

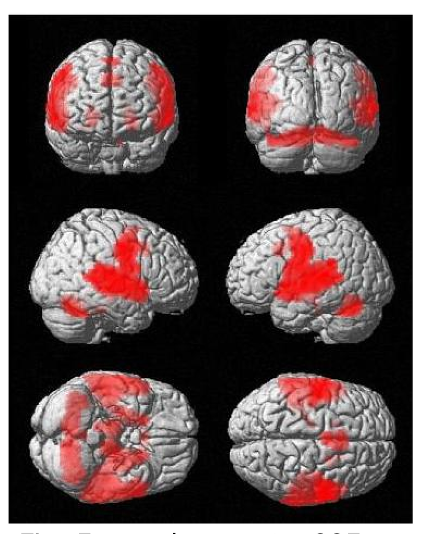
Fig. 5: words > rest; .005 (FWE), T = 6.43

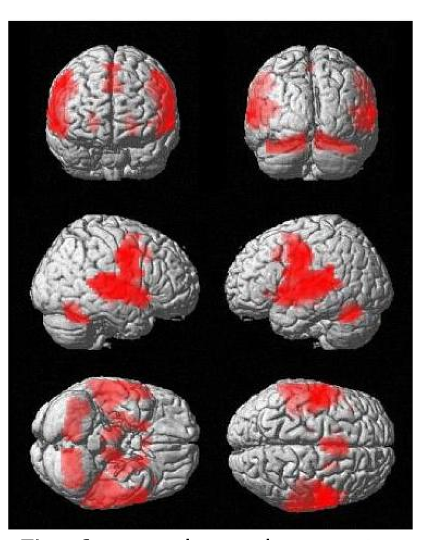
Fig. 6: pseudowords > rest; .005 (FWE), T = 6.46

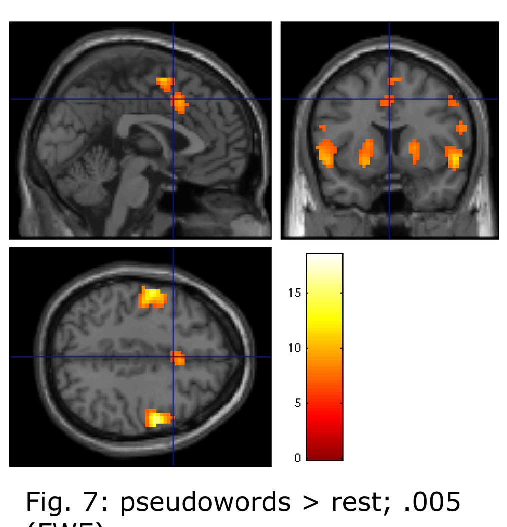
Fig. 7: pseudowords > rest; .005 (FWE)

Results

General results

There was no effect of length and only a small effect of handedness in the right putamen (see Fig. 4). Hence di- and trisyllabic stimuli and the data of right- and left-handed subjects were analyzed together.

Main effects

words > rest, pseudowords > rest

Compared to the resting state, repetition of both words (Fig. 5) and pseudowords (Fig. 6) activated bilateral primary and secondary auditory areas, the left inferior frontal gyrus (BA 44), bilateral motor areas, SMA, the mid cingulate gyrus (Fig. 7), cerebellum, basal ganglia, thalamus and other subcortical regions.

Specific effects

pseudowords > words

Contrasted to words, pseudowords activated left hemispheric regions (Fig. 8), including left inferior frontal gyrus (BA 44) and the ventral premotor cortex, BA 45 and the ant. insula (see Fig. 9), as well as the left post. sup. temporal sulcus, the left ant. sup. temporal gyrus and the SMA.

words > pseudowords

Activation for words contrasted to pseudowords was stronger than vice versa (Fig. 10 and Fig. 11). The parieto-temporal cortex was bilaterally activated including supramarginal gyrus and angular gyrus, the bilateral mesial cortex including the precuneus, post. and mid cingulate gyrus, the rostral and dorsolateral prefrontal cortex including sup. and middle frontal gyrus as well as lateral and medial parts of the frontal pole, the left cerebellum as well as bilateral ant. temporal areas, post. insula, thalamus and brainstem. A good portion of the activation shown for words is due to deactivation for pseudowords (see Fig. 12 and 13).

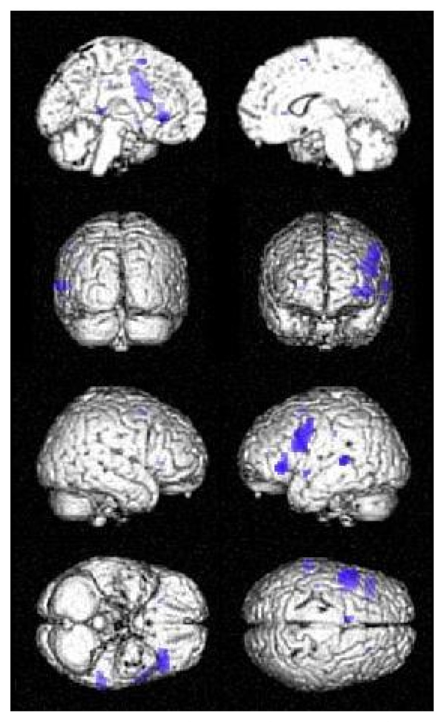
Fig. 8: pseudowords > words; .001 (unc.), T = 3.17

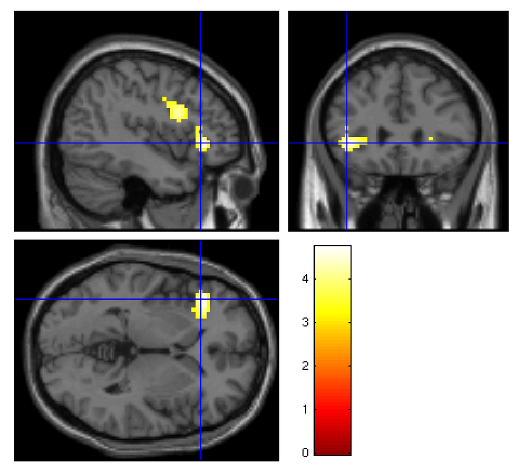
Fig. 9: pseudowords > words; .001 (unc.)

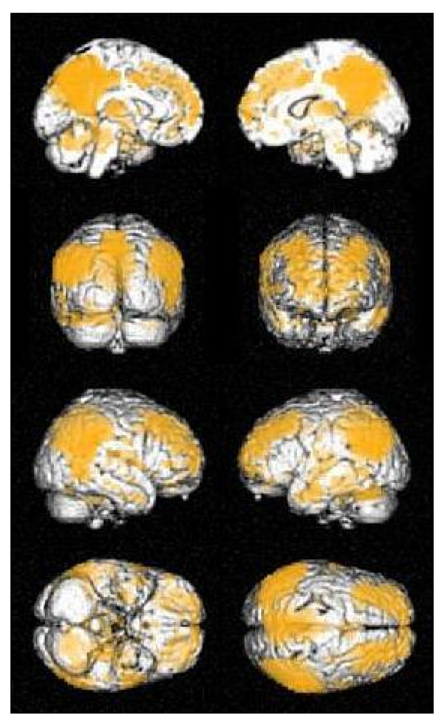
Fig. 10: words > pseudowords; .001 (unc.), T = 3.17

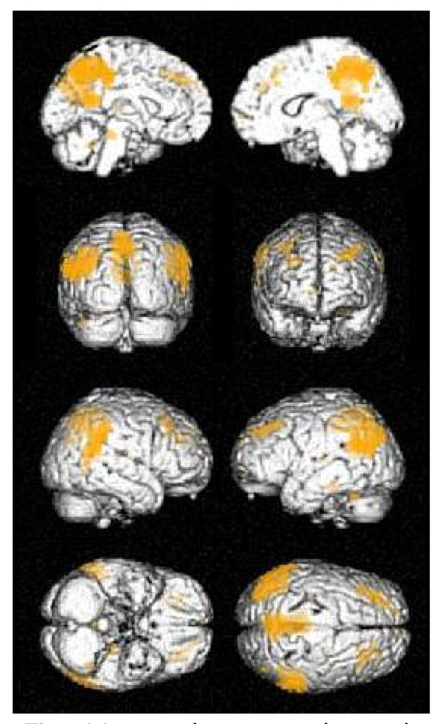
Fig. 11: words > pseudowords; .05 (FWE), T = 4.86

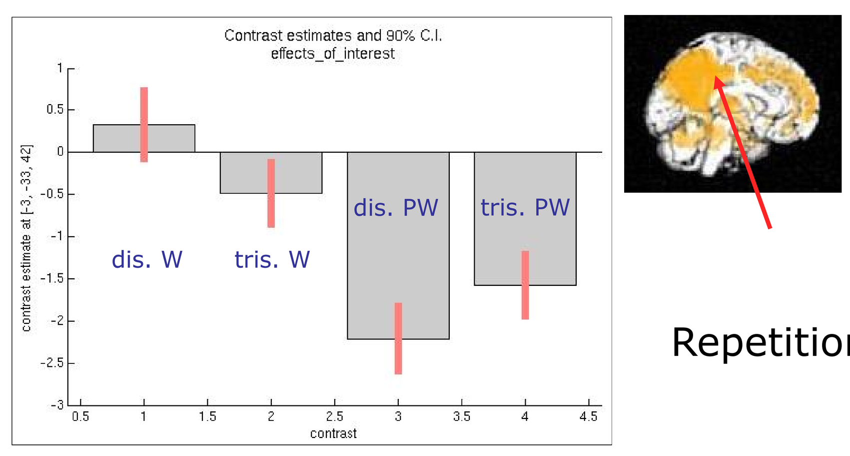

Fig. 12: words > pseudowords; .001 (unc.), [-3; -33; 42] (dis. = disyllabic, tris. = trisyllabic, W = words, PW = pseudowords).

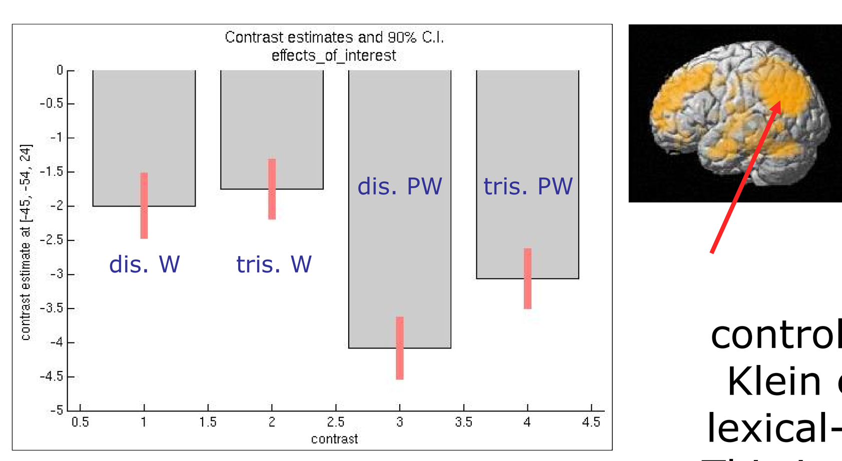

Fig. 13: words > pseudowords; .001 (unc.), [-45; -54; 24] (dis. = disyllabic, tris. = trisyllabic, W = words, PW = pseudowords).

Conclusion

Repetition of words and pseudowords involves bilateral auditory and motor processing.

Contrasting pseudoword repetition with word repetition shows a clear left hemispheric activation of brain areas associated with articulatory planning and phonological processing. This corroborates the assumption that the unsuccessful search for a lexical entry in pseudoword repetition leads to higher demands on phonological processing (cf. Castro-Caldas et al., 1998). Furthermore, the production of a new phoneme sequence has an impact on articulatory planning and motor control and is driven by ventral premotor regions (cf. Klein et al., 2006). There are no neural correlates of lexical-semantic processing or semantic associations. This implies the exclusive involvement of a nonlexical route in pseudoword repetition.

Contrasting words with pseudowords reveals differences in parieto-temporal areas associated with lexicon and semantics, which are mainly due to deactivations for pseudowords (see Fig. 13). This may indicate that semantic processing also occurs during resting state but is not required for pseudoword repetition at all. From a cognitive point of view, the involvement of a nonlexical route in word repetition (Hanley et al., 2004; see also Dell et al., 2007) is underpinned by our fMRI-data.

References

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