Processing of high and low imagery words in working memory

Preliminary results of a 7T functional MRI study

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Paivios *Dual Coding Theory* (Paivio, 1971) postulates that both visual and verbal information are processed differently and in distinct channels. Several behavioral studies have found evidence for this assumption. For instance, it has been demonstrated that verbal learning and recall is easier for words like "chair" or "table" when the learner can visualize the verbal information (high imagery words) than for low imagery words (e.g., "peace", "formula") (Pavio, 1969). However, relatively little is known about the neural correlates of potential imagery effects on working memory functioning. In our study we investigated the functional neuroimaging correlates of the interaction between the degree of imagery of words and working memory load, using the well-established experimental n-back paradigm (c.f. Owen et al., 2005).

Method

Participants: 20 right-handed participants (13 female), age 20 to 31 years (M=25,2; SD=2,63), without any known psychiatric or neurological disorders.

Material: 40 words of 4-5 letters length differing in their degree of imagery (selected from Baschek et al., 1977) were presented in an n-back task. Each stimulus was presented for 1 s followed by a 2 s inter-stimulus interval. In analogy to Braver et al. (1997), the working memory load was varied by raising the n in the n-back task from 0 to 3 items (see fig. 1). In the 0-back condition, participants were asked to decide if a presented stimulus was equal to a given target word. In the 1-,2- and 3-back conditions, the target word was any word identical to the one presented 1, 2 or 3 positions back, respectively. In each list of 20 stimuli, a number of non-target repeats were included as distractors. For each n-back condition, two lists were presented containing high or low imagery words. Therefore one trial consisted of 8 lists covering every n-back condition and both high and low imagery words. In three trials, a total of 480 stimuli were presented to the participants. The experiment is based on a full repeated measurement design.

Image acquisition and analysis: Functional images were acquired using a scientific 7 Tesla whole-body scanner (Magnetom 7 T, Siemens Healthcare, Germany) using an 8-channel head coil (Rapid Biomedical, Würzburg, Germany). We acquired whole-brain images, with a TR of 2350 ms and a TE of 22 ms. Using a 128x128 matrix, slice thickness was 2.5 mm. Functional images were preprocessed and analyzed using SPM 2. At the second level of the analysis, one-sample t-tests were computed using the single-subject contrasts. Contrasts shown here are significant at p< 0.001 uncorrected.

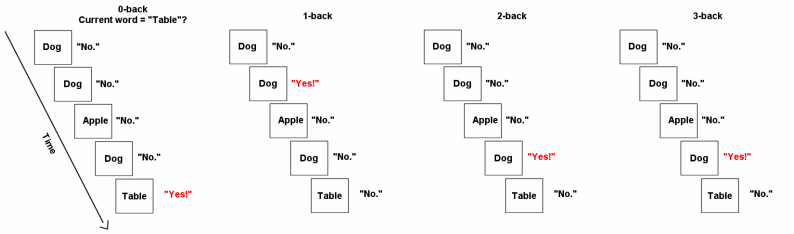


Fig. 1: The n-back paradigm: We used four versions of the task: 0-back (no working memory load), 1-back (lowest working memory load), 2-back (moderate working memory load), 3-back (highest working memory load).

Results

Behavioral data

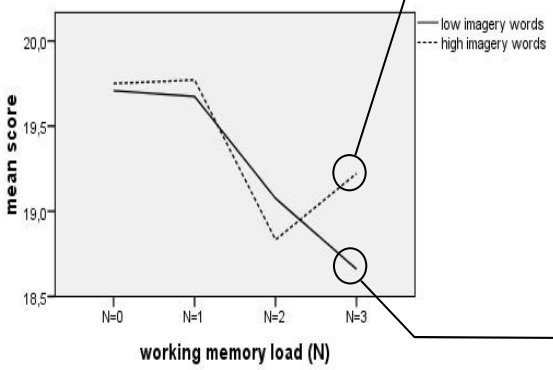


Fig. 2: Mean number of correct answers (score) plotted against working memory load (N) for low and high imagery words (N=20): Only in the 3-back task, the mean number of correct responses in the high imagery condition (M=19.2, SD=0.1) is better than that for low imagery words (M=18.7, SD=0.2, p<0.05).

Functional data

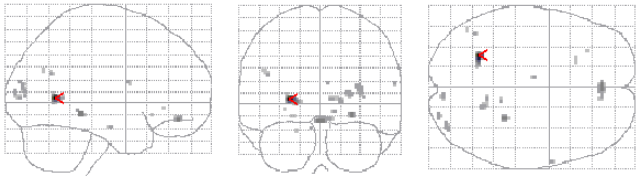
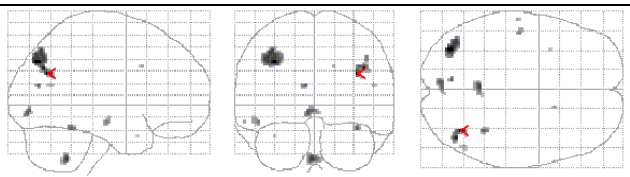
High imagery stimulus words	
Activation in the …	… medial (BA 10, 11) and inferior (BA 47) frontal gyrus, fusiform gyrus (BA 47), precentral gyrus (BA 6), angular gyrus (BA 39), middle temporal gyrus (BA 39), parahippocampal gyrus (BA 30, 18), lingual gyrus (BA 17, 18), middle occipital gyrus (BA 18) and cuneus (BA 18).
Low imagery stimulus words	
Activation in the …	… cingulate gyrus (BA 32), precuneus (BA 39, 19), superior (BA 38), inferior (BA 20) and middle temporal gyrus (BA 39), sub-gyral (BA 20), fusiform gyrus (BA 37), lingual gyrus (BA 18) and cuneus (BA 18).

Fig. 3: Contrasts and regions of activation for low and high imagery stimulus words under the high working load condition (3-back, N=20). All contrasts are significant at p<0.001 uncorrected.

Discussion

The behavioral data (see Fig. 2) show that under conditions of high working memory load high imagery words are better remembered than low imagery words. In the analysis of the functional images (see Fig. 3), we found activations in the dorsolateral (BA 46, BA 9) and ventrolateral (BA 47) prefrontal cortex, in frontal pole (BA 10), in the medial posterior parietal (BA 7) and inferior parietal lobe (BA 40). This is in accordance with Owen et al.'s (2005) meta analysis about activation found when using the n-back paradigm to investigate neural correlates of working memory. When looking at potential differences between activation patterns found for high vs. low imagery words it seems reasonable to contrast the conditions in which differential patterns on a behavioral level have emerged. In our study, this was the case in the condition with the highest working memory load (3-back). On a descriptive level, comparing the activations found for high vs. low imagery words in the highest minus no working memory loads (3-back minus 0-back), more activation can be found bilaterally in the parietal lobe – in particular in the precuneus - when the stimulus material is of a lower degree of imagery. This is an interesting finding, as the precuneus is also known to play a crucial role in visualizing episodic memories (Cavanna et al., 2006). It might be that under our highest working memory load condition with low imagery stimulus material, the human brain tries to "visualize the unvisualizable" (using a lot of effort). In contrast to this, under the obviously easier condition (same high n in the n-back task but stimulus material with a higher degree of imagery) the brain still seems to have the resources to try to categorize its input, as the frontal activation indicates. These results and accordingly the interpretation are preliminary and have to be confirmed by further analysis.

However, the results also show that we might not have reached a sufficiently high working memory load. Both mean number of correct answers and hemodynamic responses indicate that verbal stimuli in an n-back task should have a facilitating effect on the performance. This effect of the degree of imagery appears not earlier as in the 3-back condition, which – according to other studies using the n-back paradigm with letters or number - should have been a most demanding condition. In our case it would have been necessary to conduct conditions of 4- and 5-back on the one hand to reach a maximum working memory load, and thereby see the diverging effect of the degree of imagery of words both in the behavioral and functional data.

References:
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