The effect of word concreteness on recognition memory

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Received 29 March 2006; revised 24 May 2006; accepted 9 June 2006
Available online 24 July 2006

Concrete words that are readily imagined are better remembered than abstract words. Theoretical explanations for this effect either claim a dual coding of concrete words in the form of both a verbal and a sensory code (dual-coding theory), or a more accessible semantic network for concrete words than for abstract words (context-availability theory). However, the neural mechanisms of improved memory for concrete versus abstract words are poorly understood. Here, we investigated the processing of concrete and abstract words during encoding and retrieval in a recognition memory task using event-related functional magnetic resonance imaging (fMRI). As predicted, memory performance was significantly better for concrete words than for abstract words. Abstract words elicited stronger activations of the left inferior frontal cortex both during encoding and recognition than did concrete words. Stronger activation of this area was also associated with successful encoding for both abstract and concrete words. Concrete words elicited stronger activations bilaterally in the posterior inferior parietal lobe during recognition. The left parietal activation was associated with correct identification of old stimuli. The anterior precuneus, left cerebellar hemisphere and the posterior and anterior cingulate cortex showed activations both for successful recognition of concrete words and for online processing of concrete words during encoding. Additionally, we observed a correlation across subjects between brain activity in the left anterior fusiform gyrus and hippocampus during recognition of learned words and the strength of the concreteness effect. These findings support the idea of specific brain processes for concrete words, which are reactivated during successful recognition. © 2006 Elsevier Inc. All rights reserved.

Introduction

There is strong evidence from behavioral studies that the cognitive processing of concrete and highly imageable words is superior to that of abstract words.1 A positive effect of word concreteness has been shown for a variety of tasks including episodic long-term memory (Jessen et al., 2000), continuous recognition (Klaver et al., 2005), lexical decision (Bleasdale, 1987) and working memory (Van Schie et al., 2005).

Two competing sets of theories try to explain the differences in processing of concrete and abstract words. Multiple-coding approaches, like the dual-coding theory, claim that concrete words are not only encoded verbally, but that they are also represented non-verbally in an image based system (for a comprehensive overview, see Paivio, 1986). On the other hand, single-mode models, like the context-availability theory, try to explain the superiority of concrete word processing based only on differences in verbal processing claiming that concrete words can be more easily put into a semantic context (Schwanenflugel et al., 1991).

Obviously, the hypotheses derived from these theories are well suited for being addressed by neuroimaging techniques because they make specific predictions about activation pattern differences between the two groups of words. If there was any “dual coding” of concrete words, an activation of image-processing brain areas would be expected, when comparing concrete to abstract word processing. On the other hand, single-mode models predict activation differences between concrete and abstract words restricted to language processing brain areas.

Presently, there is converging evidence that when compared to concrete word processing, abstract word processing is associated with higher activation in left hemispherical areas that are known to be involved in semantic processing, i.e., the left inferior frontal gyrus (LIFG) (Perani et al., 1999; Jessen et al., 2000; Fiebach and

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1 A common definition of the word concreteness encompasses the extent to which a word refers to features of objects or persons that can be sensually experienced. Imageability, on the other hand, can be defined (and was defined as such in our study instruction) as the ability of a word to elicit internal images. Thus, imageability is an important subfeature of concreteness and ratings of word concreteness and imageability are highly correlated (Baschek et al., 1994). For convenience, the two labels are used synonymously throughout this article.
and the superior temporolateral cortex (Mellet et al., 1998; Kiehl et al., 1999; Wise et al., 2000; Binder et al., 2005). The opposite comparison yielded much more variable results, with some studies lacking to find any areas activated more during concrete word processing at all (Kiehl et al., 1999; Perani et al., 1999). Some authors find more bilateral activations during concrete processing (Binder et al., 2005), while other studies failed to show a specific, right-hemispheric component (Fiebach and Friederici, 2004). Quite consistently, studies find an activation of left hemispheric regions associated with higher levels of visual processing like the left fusiform gyrus (D’Esposito et al., 1997; Mellet et al., 1998; Fiebach and Friederici, 2004).

In this context, the investigation of episodic memory is of special interest because there is evidence that episodic memory processes are content-specific. For example, items being learned as pictures elicit different patterns of brain activation (i.e. in visual processing areas) during recollection than do words, even when only words are presented during the retrieval period (Woodruff et al., 2005). These findings support the so-called reinstatement hypothesis, which states that recollection of memory contents is associated with a reactivation of brain areas which were active during encoding. Thus, if there is brain activity specific for processing concrete words that underlies the concreteness effect in memory, as dual-coding theory predicts, one would expect to find a similar pattern of activation during both encoding and recollection.

Therefore, we investigated the neural mechanisms underlying the word concreteness effect during encoding and retrieval in a recognition memory paradigm. Specifically, we wanted to test: (1) whether the same pattern of left hemispherical activation described for abstract vs. concrete words is also present during memory encoding and retrieval; (2) which pattern emerges for the concrete vs. abstract comparison during encoding and retrieval and most importantly; (3) how these activations relate to successful memory formation and retrieval.

Methods

Subjects

Twenty-one subjects without any history of neurological or psychiatric disease were enrolled (12 female; mean age 27.4 years (±6.2); range 19–43 years). All subjects were right-handed according to the Edinburgh Handedness Scale. All subjects gave written informed consent and the study was approved by the local ethics committee.

Materials

We selected all simple (non-composite) nouns with a word length between 2 and 10 characters and a word frequency between 6 and 150 per million from a comprehensive database of German words (CELEX). These 1006 words were rated for their imageability by ten healthy subjects who did not participate in the fMRI experiment. The rating was on a 7-point Likert scale ranging from 1 to 7 using a standardized instruction. Out of the third with the highest and with the lowest imageability rating, 180 concrete and 180 abstract words were chosen, excluding synonyms and parallelizing the two word groups for word length and word frequency. The mean word length was 5.1 (±1.2) for concrete and 5.2 (±1.3) for abstract words (t = 0.75, n.s.); the mean word frequency was 28.9 (±29.6) for concrete and 33.2 (±32.1) for abstract words (t = 1.32, n.s.); and the mean imageability rating was 6.3 (±0.4) for concrete and 2.5 (±0.5) for abstract words (t = 78.0, P < 0.0001).

Task

During the encoding period, the subjects viewed 90 concrete and 90 abstract words randomly selected from the full list of words. The stimulus duration was 1 second (s), the interstimulus interval (ISI) was jittered between 4.5 s and 7.5 s with a fixation cross displayed. The subjects were informed that a recognition task would follow and they were asked to remember the words as well as possible. The duration of the encoding period was approximately 23 min. Between the encoding period and the recognition period, there was a break of approximately ten min during which the subjects could either leave the scanner or were subjected to a structural scan.

During the recognition period, the subjects saw the 180 words of the encoding period randomly intermixed with the other 180 words of the full list which were used as distractors. They made an old/new-decision by pressing one of the four response buttons found on the hand grips (Nordic NeuroLab, Bergen, Norway) indicating whether they thought that a word was definitely old, probably old, definitely new or probably new. Again, the stimulus duration was 1 s with an ISI of 4.5–7.5 s during which the response could be given. The duration of the recognition period was 45 min.

For behavioral analysis, hits were defined as studied words that were confidently recognized; misses as studied words that were confidently judged to be new; correct rejections as new words which were confidently judged to be new; and false alarms as new words that were confidently judged to be old. As the main behavioral outcome measure, the corrected recognition rate (hits—false alarms) for concrete and for abstract words were compared across subjects with a dependent measures t-test. Only confidently given judgments were used. Reaction times for the old/new-decision during recognition were compared by independent samples t-test.

fMRI data acquisition

The scanning was performed on a 1.5 T Avanto Scanner (Siemens, Erlangen, Germany) using a standard 8-channel head coil. During encoding and recognition, axial echo planar imaging (EPI) scans were acquired (426 and 842 scans, respectively) each including eight dummy scans. Scan parameters were: number of slices: 35; slice thickness: 3 mm; interslice gap 0.3 mm; matrix size: 64 × 64; field of view: 192 mm; echo time (TE): 50 ms; repetition time (TR): 3 s. The task was presented via video goggles (Nordic NeuroLab, Bergen, Norway) using E-prime presentation software (Psychology Software Tools; www.pstnet.com).

fMRI data analysis

The fMRI data analysis was done using Statistical Parametric Mapping 2 (SPM2, www.fil.ion.ucl.ac.uk/spm/). The preprocessing included realignment with unwarping, slice timing, normalisation to a standard EPI template and smoothing with a 12 mm Gaussian kernel. Re-sampled voxel size (after normalisation) was 3 × 3 × 3 mm. The hemodynamic response was modelled by a canonical hemodynamic response function and the temporal
derivative. For fMRI analysis, correct answers were defined as previously stated (i.e. confidently given old judgements for old words = hits; confidently given new judgements for new words = correct rejections), whereas for mistakes unconfidently given wrong answers were also counted (i.e. all old judgements for new words = false alarms; all new judgements for old words = misses). This was necessary because otherwise the number of events in each category would have been too small in many subjects. Correct responses which were not given confidently were modelled separately and were not included in the statistical analysis.

For modelling the encoding period, six vectors of stimulus onsets were used (abstract/concrete words that were either hits, misses or correct responses not given confidently). When modelling the recognition period, ten different vectors were constructed (abstract/concrete words that were hits, misses, correct rejections, false alarms or correct responses not given confidently). Parameter images for the respective contrasts of interest were generated for each subject and were then subjected to a second-level random effects analysis using a one-way analysis of variance (within-subject ANOVA) as a model. The predefined linear combinations of the group contrast images were then tested with a one sample t-test against a null hypothesis of no effect. The main contrasts were defined as follows (in brackets given the experimental part):

### Word type effects
Concreteness effect: concrete > abstract words
Abstractness effect: abstract > concrete words

### Memory effects
Subsequent memory effect (learning): hits > misses
Negative subsequent memory effect (learning): misses > hits
Old/New-effect (recognition): hits > correct rejections
New/Old-effect (recognition) correct rejections > hits

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Table 1
Memory performance and reaction times (RT) for concrete and abstract words

![Fig. 1. Statistical parametric t-map for abstract > concrete words (a) and hits > misses (subsequent memory effect) (b) during encoding (threshold \( P < 0.001 \), projected onto a 3D-reconstruction of a canonical single subject brain.)](image)
Positive memory effect (recognition): hits > misses
Negative memory effect (recognition): misses > hits

Interactions between the word type effects and the different memory effects were calculated accordingly. The statistical threshold was set at a $P$-value of 0.001 voxelwise (uncorrected) with a cluster extent of $>9$ contiguous voxels and only clusters at $P<0.05$ at the cluster level (corrected for multiple comparisons) were considered significant. To test for regional overlaps between word type and memory effects, word type effects (threshold $P<0.001$) were inclusively masked with the memory effects with a mask $P$-value $<0.05$. To more specifically test for differences in memory effects for the two word types the separate old/new-effect for abstract and concrete nouns during the recognition period (threshold $P<0.001$) were inclusively masked with word type effects from the encoding period (mask threshold $P<0.05$).

To test for brain areas associated with inter-individual differences in the memory concreteness effect, a second-level correlation analysis was performed. The t-maps for the subsequent memory effect during learning and the old–new effect during recognition were correlated with the extent of the concreteness effect over subjects. The extent of the concreteness effect was defined as the corrected recognition rate for concrete words minus corrected recognition rate for abstract words. For this analysis, activations of at least ten adjacent voxels at a significance level of $P<0.001$ without any further correction were interpreted.

Anatomical cluster labelling was done using the Anatomical Automated Labeling Tool for SPM (Tzourio-Mazoyer et al., 2002). For the transformation of MNI-coordinates in Talairach (TAL)-Coordinates we used non-linear transformation according to: http://www.cbu.cam.ac.uk/imaging/common/mnispace.shtml.

Results

Memory performance

The corrected recognition rate (hits–false alarms) was significantly higher for concrete words than for abstract words ($50.6\pm21.9\%$ vs. $42.1\pm22.2\%$, $t=3.0$, $P=0.007$). This difference was mainly based on a significantly smaller rate of false alarms for concrete words than for abstract words ($9.1\pm7.5\%$ vs. $13.4\pm9.0\%$, $t=-2.7$, $P=0.015$), whereas the rate of hits did not differ significantly ($59.7\pm19.4$ vs. $55.6\pm18.9$, $t=1.6$, n.s.). The percentage of correct rejections and misses did not differ significantly either. The reaction times for the old/new-judgement were significantly shorter for concrete words than for abstract words ($1600\pm714\ \text{ms}$ vs. $1642\pm713\ \text{ms}$, $t=2.5$, $P=0.013$). Detailed results are shown in Table 1.

fMRI-data

Encoding

The contrast abstract vs. concrete words yielded a significant activation of the left inferior frontal gyrus (Brodmann Area (BA) 45) (Fig. 1, Table 2). There were no areas displaying significant activation for the opposite contrast. The comparison of subsequently remembered (hits) versus forgotten words (misses) (subsequent memory effect) showed four clusters of activation bilaterally in the inferior and middle frontal gyri (Fig. 1, Table 2). There was no significant activation for the opposite contrast (negative subsequent memory contrast). The area activated by the abstract vs. concrete contrast was overlapping with the left inferior frontal area seen with the subsequent memory contrast so that after inclusively masking the first contrast with the latter, this area still showed significant activation (Fig. 2). Left inferior frontal activation was also found when the subsequent memory contrast for abstract words alone was masked with the contrast abstract vs. concrete words, although this comparison was not significant at a cluster level. There were no significant interactions between word type and memory effects.

Recognition

During recognition, the activation pattern for the abstract vs. concrete words was similar to that during encoding with a significant activation of the triangular part of the left inferior frontal gyrus (BA45) (not shown). The concrete vs. abstract contrast showed a bilateral posterior activation involving the angular gyrus on both sides, together with parts of the inferior parietal lobe on the left side. Besides hand-motor activity for the button presses on one side, the old/new-effect yielded a

| Brain region | TAL-coordinates $n$ $z$ $P$ |
|--------------|---------------------|--|---|
| L. inferior frontal g. (BA 45) | 50 21 | 7 | 131 | 4.25 | 0.016 |
| L. inferior frontal g. (BA 44) | 45 22 | 17 | 8 | 128 | 3.95 | 0.003 |

Table 2
Activation clusters for main effects

Brain regions and TAL-coordinates of activation maxima. Note that only clusters that were significant on a cluster level of $P<0.05$ (corrected for multiple comparisons) are listed. Local maxima of subclusters are listed when they are more than 8 mm apart from the main peak activation. $n=$ number of suprathreshold voxels, $z=$ z-score at peak activation, $P= P$-value for the cluster (corrected for multiple comparisons).

References

For full references please see the original article.
widespread activation in the left precuneus/cuneus, left cerebellar hemisphere, right rolandic operculum, left angular gyrus, left supramarginal gyrus, right anterior cingulum, left and right ventral caudate and the frontal inferior triangular gyrus (for details, see Table 2). The positive memory contrast was characterised by a very similar pattern of activation as the latter. Hence, exclusively masking either of the two effects with the other at a mask level of $P<0.05$ left no significant activations exclusively present in either contrast. The converse contrasts (new/old and negative memory effect) did not show any significant activation besides that for hand motor activity. Again, no significant interactions between word type effects and memory effects were found.

When inclusively masking the concrete vs. abstract contrast with the memory contrasts, the left inferior parietal and angular activation was consistently significant at a cluster level (Fig. 3). This was regardless of whether masking was done with the memory contrasts for all words or for each word category separately. The right-sided posterior activation also persisted when masked with the memory contrasts, but lost significance at the corrected $P<0.05$ level after the masking procedures.

When inclusively masking the old/new-effect for concrete words with the contrast between concrete and abstract words from the encoding period, four regions displayed significant activation: Bilateral precuneus, left cerebellar hemisphere, bilateral posterior cingulate cortex and bilateral anterior cingulate cortex (Fig. 4, Table 3). For abstract words no significant activation was observed after the respective masking procedure.

The correlation analysis of the behavioral concreteness effect with the different memory contrasts yielded a positive correlation with the activation for the old/new-contrast during recognition in the left medial temporal lobe (left fusiform gyrus/
hippocampus). That is, subjects activating this region stronger during the correct recognition of studied words had a larger memory benefit from word concreteness (Fig. 5).

**Discussion**

In this study we investigated the positive effect of word concreteness on recognition memory by using fMRI. We found that intentional encoding of abstract vs. concrete words was associated with a stronger activation of the left inferior frontal gyrus (LIFG). The same region was associated with a positive subsequent memory effect. During encoding we found no areas that were activated more strongly by concrete words on our predefined significance level. During recognition there was a stronger bilateral activation of inferior parietal regions for concrete vs. abstract words. The left-sided parietal activation was associated with the correct identification of studied words. Additionally we observed precuneal, cerebellar and cingulate activations associated with correct identification of studied concrete words that also distinguished concrete from abstract word processing during encoding. Furthermore we found a correlation between brain activation in the left fusiform gyrus and hippocampus with the strength of the behavioral concreteness effect across subjects.

A stronger activation of the LIFG has been found in a number of studies for a variety of different tasks (Perani et al., 1999; Fiebach and Friederici, 2004; Noppeney and Price, 2004; Binder et al., 2005) including memory encoding (Jessen et al., 2000). The same region is also more strongly activated during the processing of low vs. high frequency words and words learned late in life compared to words learned earlier (Fiebach et al., 2003). This area furthermore shows task-dependent activation in semantic vs. syntactic processing (Friederici et al., 2003). Thus, there is converging evidence in literature that this region is critical for the effortful retrieval of information from a semantic knowledge system.

The fact that the LIFG is more strongly activated by abstract words is somewhat ambiguous with regard to its meaning for the behavioral effects of word concreteness and the theories trying to explain them. It could either signify that for concrete words, access to semantic knowledge is easier than for abstract words, as context availability theory would predict. In this case, the stronger activation of semantic processing areas would be the result of a more effortful semantic processing for abstract words. An alternative explanation in line with the dual-coding theory would be that processing of concrete words does not only rely on a semantic code, but also on a hypothetical image-based code, and as a consequence semantic processing is less important when dealing with concrete words. A prediction of context-availability theory on the behavioral effect of word concreteness is the easier access to semantic knowledge for concrete words as the underlying mechanism for their facilitated cognitive processing. In this case, one would expect a brain activation which is based on the difficulty of semantic processing to be associated with a lower performance level. In our study, however, the opposite is true. A stronger activation of the LIFG is found in parallel for the abstract vs. concrete effect and the subsequent memory effect. A possible interpretation of the data is that abstract words require stronger...
semantic processing than concrete words as a premise for successful encoding. One possible explanation for this could be a supportive role of other brain areas for the encoding of concrete words. However, our encoding data offer no positive evidence for this assumption since there were no additional brain areas activated more strongly by concrete words.

During recognition we observed stronger bilateral activation of the inferior parietal cortex and the angular gyrus for concrete vs. abstract words. This finding is in line with a recent study on concrete word processing without memory retrieval (Binder et al., 2005). Our study design allowed us to show that the left parietal activation was also associated with successful recognition irrespective of word type. This finding is not unexpected since this region is often found to be associated with correct recognition in recognition memory paradigms (e.g., Weis et al., 2004; Henson et al., 2005). More precisely, the region found in our study roughly corresponds to a region proposed to be specific for the recollection of a memory as opposed to mere familiarity (Wheelier and Buckner, 2004). The interpretability of this activation is limited by the fact that it could have reflected differences in memory level for concrete and for abstract words. However, this activation is also present for correctly rejected concrete vs. abstract words during recognition. Thus, this activation seems to be driven not only by the correct identification of studied words, but also by the processing of concrete words per se under a recognition task. This could mean that concrete words might be better suited to evoke specific contextual information, which is supposed to be the basis of recollection.

More direct evidence for brain regions being differentially involved in encoding and retrieval of concrete and abstract words was found by another masking procedure using the word type effects from the encoding period as a mask for the word type specific old/new-effects during retrieval. For concrete words, this analysis yielded significant activations in the left and right anterior precuneus, the left cerebellar hemisphere, and bilateral posterior and anterior cingulate cortex. The finding of a precuneous activation is in line with findings from classic PET (Fletcher et al., 1996) and fMRI studies (Henson et al., 1999) that suggested a role for the precuneus in the retrieval of imageable material. Meanwhile, studies have suggested a functional dissociation within the precuneus, with a more posterior region being involved in retrieving more abstract contents, and a more anterior region being involved in the retrieval of more visual contents (Lundstrom et al., 2003, Woodruff et al., 2005). The bilateral region found to be more strongly involved in successful retrieval of concrete vs. abstract words in our study corresponds to the latter. Stronger activations in this region were also present during the intentional encoding of concrete as compared to abstract words, which is in line with previous studies on concrete word processing (Binder et al., 2005). This finding supports the idea of a (content specific) reinstatement of neuronal activity from the encoding period while successfully retrieving this information. It furthermore supports the notion of an additional imagery-based system for the encoding of concrete words, as proposed by dual-coding theory, although the role of the precuneus in this context must be further clarified (for a recent review, see Cavanna and Trimble, 2006). It must also be stressed that our results do not show that the specific reinstated brain activities are necessary for successful recollection—they could also be interpreted as a consequence of retrieval success (for a more detailed discussion of this aspect see Woodruff et al., 2005).

Activations of the cerebellar hemispheres during episodic memory retrieval have been described before in a number of studies (e.g., Weis et al., 2004, Cabeza et al., 2002). However, the exact role of the cerebellum in recognition memory is poorly understood. Since cerebellar lesions do not have a major impact on memory performance, a rather unspecific supporting role is widely assumed. With respect to concrete word processing, cerebellar activity has not been reported, which could be partly due to the fact that the cerebellum is rarely fully covered in imaging studies. Because the cerebellum is known to be involved in motor imagery (Ross et al., 2003), we speculate that this activation is due to the induction of imagined manipulations by concrete words such as tools. This question could be further addressed by a more specific item selection that allows a distinction between different classes of concrete words.

Posterior and anterior cingulate activations have also been linked to retrieval success in previous studies. Posterior cingulate activations are regularly found in combination with precuneal and

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Fig. 5. Left: statistical parametric t-map for the correlation between estimates of the old/new effect and the behavioral concreteness effect (P<0.001), projected onto a canonical single subject T1-weighted image. Right: scatterplot of the contrast estimates against the concreteness effect (corrected recognition rate for concrete words minus corrected recognition rate for abstract words) at the activation maximum (TAL-coordinates −33, −10, −20).
left lateral parietal activations (Wagner et al., 2005) and might reflect similar processes as discussed previously. Anterior cingulate activations in a recognition memory context are generally assumed to reflect decision-making processes when translating the recognition evaluation into a response (Fleck et al., 2006). A stronger activation of this area by concrete than by abstract words has been described in one early study (D’Esposito et al., 1997). As is the case for the other activations described before, we cannot rule out the possibility that common activation in this area during retrieval of concrete words and during online processing of concrete words in the encoding period reflects different cognitive processes that are not functionally linked.

Another hint at a brain region involved in the memory concreteness effect comes from the correlation of brain activity with the behavioral data. Subjects displaying a larger concreteness effect showed a stronger activation in the left anterior fusiform gyrus and the left hippocampus when correctly identifying learned words. The left middle and anterior fusiform gyrus has been repeatedly reported to be associated with the retrieval of visual object information (Wheeler and Buckner, 2003; Price et al., 2003) rather than with immediate object perception. It is also more strongly activated during the recollection of studied pictures as compared to studied words, even when the test items are words (Woodruff et al., 2005; Wheeler and Buckner, 2004). Although the activation found in our study lies even more anterior within the fusiform gyrus than in most of these studies, we assume it to be a correlate of the retrieval of visual information. This finding can be interpreted in accordance with both context-availability theory and dual-coding theory. On the one hand, it shows that the retrieval of contextual information is important for the concreteness effect. On the other hand, the nature of this information seems to be primarily visual as predicted by dual-coding theory.

The finding of a concreteness effect in brain activation during recognition, but not during encoding, may result from different mechanisms. One explanation is simply that of statistical power: during recognition, twice as many events could be analysed than during encoding. Another reason could be the different task demands: the intentional learning instruction under the encoding task and the recognition task. Since the parietal areas for reasons might be that different processes are activated by the encoded words. An fMRI study of concrete and abstract words. Neuroimage 19, 1627–1637.


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