Representation of Abstract and Concrete Words:

A Functional Neuroimaging Study

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Abstract

Dual code theory and context availability theory are the leading theories describing why concrete words have a processing advantages over abstract words. This difference between concrete and abstract words has been called the concreteness effect. This paper examines the underlying neural representation of abstract and concrete words. We hypothesized that abstract words would increase neural activation in the left inferior frontal gyrus, and that concrete words would increase neural activation in the precuneus. Using two region of interest analyses we conducted two separate one sampled t-test one for the left inferior frontal gyrus in the abstract > concrete contrast, and one in the precuneus for the concrete > abstract contrast. The left inferior frontal gyrus was more active ($M = 0.356$ $SD = 1.106$) during processing of abstract words compared to concrete words $t(53) = 2.366$ $p > .05$. We found no difference in activation in the concrete > abstract contrast in the precuneus. Our results support the context availability theory, however due to our statistical choices our results should not be extrapolated, but only used as a pilot study.

Introduction

The *concreteness effect* is a term referring to the behavioral findings that concrete words (CW) are retrieved more easily from long term memory than abstract words (AW) (Yui et al., 2017), and processed faster (Kumar & P, 2012). This apparent difference between CW and AW has been a hot topic for cognitive neuroscience research, which has led to two distinct theories that can account for the concreteness effect.

Dual code theory, proposed by Allan Paivio (1991), states that the way we represent information in the mind is through two separate cognitive systems, that are connected. These two systems are called the non-verbal system (NVS) and the verbal system (VS). The NVS relies on mental images while the VS relies purely on linguistic features and associations between similar verbal concepts. It should be noted that the dual code theory has been update as time has passed. In its the present form the NVS includes all our sense, whereas the VS only includes visual (writing), auditory (speech) and haptic (Braille; a tactile writing system) sensory modalities. Dual code theory holds that CW are easier retrieved and processed because they will have access to both the NVS and the VS; whereas AW will rely solely on the VS, because they do not have a physical form or shape for the NVS. Evidence for this theory comes from findings that memory is better for things we both hear and visually see. For instance, trying to remember a certain route, you will be able to follow the route better if you have been told the route (VS) as well as seen it for yourself (NVS), compared to just having seen or been told the route separately (Clark & Paivio, 1991).

The other theory that describes the concreteness effect is called *context availability theory*. It argues that the difference in processing time between CW and AW results from a larger contextual support for CW and not from a distinct NVS (Schwanenflugel & Shoben, 1983). According to this theory, CW automatically activate more associative information, resulting in faster recognition of these words. Therefore, this theory argues that concrete and AW are processed in a similar fashion, but that CW are easier processed because they have more associations than AW have. Support for this theory comes from studies showing that processing of AW put in a meaningful context, which will make the sentences with AW have more associations, are recognized as rapidly as CW (Schwanenflugel & Stowe, 1989).

Dual code vs context availability through the eyes of neuroimaging results.

The dual code theory claims that CW activate both the VS and the NVS, which should be related to mental imagery. Furthermore, the dual code theory holds that AW should be solely processed in the VS, which could be argued would elicit a higher activation in language processing area; because the VS relies solely on linguistic features.

Context availability theory holds that processing of AW takes longer than CW, because of the increased number of associations for CW. So, one could argue that this theory holds that the language system that processes both concrete and AW will be more active when processing an AW instead of a CW. This means that both theories can be said to argue that the language system will be more active in the processing of AW compared to CW. However, the dual code theory holds that CW should elicit a higher activation in areas associated with mental imagery.

A meta-analysis from Wang et al (2010) reviewed 19 neuroimaging studies and showed a greater activity of the left inferior frontal gyrus (LIFG), left superior temporal gyrus and the left middle temporal gyrus, all areas associated with language processing (Hoffman et al., 2015); when the participants processed AW compared to CW. They also found that the left precuneus, the left posterior cingulate and the left parahippocampal gyrus were more active in the processing of CW compared to AW. These areas located in the left parietal lobe has been associated with mental imagery in function magnetic resonance studies (fMRI) (Kosslyn et al., 2001) and in transcranial magnetic stimulation studies (Sack et al., 2005), especially the precuneus has been associated with memorization of scenes, where mental imagery is necessary (Mashal et al., 2014, Mellet et al., 2000).

Hypotheses

In the present study, we hypothesize that the LIFG is more active when viewing AW compared to CW, furthermore we hypothesize that the precuneus is more active when viewing CW compared to AW. For our behavioral analysis we expect the AW to decrease reaction time compared to CW on subsequent facial image stimuli. However, we expect when including valence as a covariate that this decrease in reaction time disappears.

Methods

This experiment was a two-fold experiment. Firstly, we conducted a purely behavioral experiment, where participants looked at words and then faces. Secondly, we conducted the same experiment, where the participants were in an fMRI scanner.

Participants

67 participants, who were non-native English speakers, took part in the behavioral experiment (47 females, mean age: 23.29 years, SD: 4.12). The group that also participated in the fMRI experiment consisted of 9 non-native English speakers (6 females, mean age: 24.57 years, SD: 0.959). Participation was voluntary.

Experimental paradigm

A total of 360 words were selected from a database of 535 words that had been rated on 65 different semantic dimensions (Binder et al., 2016). The dimension *super category* was a categorical variable and was, for our analysis, dummy coded into a dichotomous variable of concreteness. There were 10 subcategories in total. Subcategories containing CW were coded as 1, and those containing AW were coded 0 (see *figure 1*). All the *super categories* that had the word *abstract* in their title were coded 0. Furthermore, *mental entity* was also coded 0. The rest of the categories were coded 1. The concrete categories contain 415 words, and the abstract categories contain 120 words.

Procedure

The participants were presented with a word on a screen. Following a break of either 3 or 5.6 seconds, they were presented with one of two emoji faces: *happy* or *fearful* (see *figure 5* in appendix). The participants then had to press the *y*-key with their middle finger if a face was fearful or the *b*-key with their index finger if a face was happy. A fearful face could only follow a negative or a neutral word, and a happy face could only follow a positive or a neutral word. This procedure was repeated with a new word 360 times over 6 sessions. The words were presented in random order, and each session lasted 10 minutes. The neuroimaging part of the experiment was conducted on a GE 3.0 Tesla scanner and each fMRI volume consisted of 45 slices. The voxel-size was: 2.53x2.53x3mm, and data was acquired with a TR = 1s (1Hz).

Data analysis

Reaction times with a z-score of ± 3 were filtered out from the analysis to account for outliers (9.5%). When looking at the behavioral data for our fMRI participants, we saw that one participant did not give an answer to 14 out of the 360 images. When you consider that the same participant did not answer to 7 images in the last session, and that no one else had more than one unanswered image, it indicates that this participant might have been unfocused. However, during our behavioral and neuroimaging analyses, we included all participants in order to maintain statistical power.

R studio

To see if the abstract/concrete scale influenced reaction time, we ran a linear mixed effects model. Data analysis and statistical models were conducted in R version 3.6.1 (R Core Team, 2019). Data was collected using PsychoPy (Peirce, 2009). Linear mixed effects models were conducted using the package lme4 (Bates et al., 2020) version 1.1.21. The lmerTest package version 3.1-2 (Kuznetsova et al., 2020) was used for model comparison. We conducted a factor analysis (FA), using the psych package (Revelle W, 2019) version 1.9.12.31 on the binder data. We found that the factor that explained the most variance was valence, because it rated highly on Binder's (2016) features like pain, fearful and angry. For models, the valence scale was used continuously, for visualization it was used dichotomously. In the dichotomy we defined low valence as below the mean value of the absolute value of valence (1.53), and high valence as above the mean value of the absolute value of valence.

SPM12

The fMRI data was analyzed with SPM12 revision 7771 (Ashburner et al., 2014). The imaging data was realigned, coregistered, segmented, normalized, (reslicing the voxels to 2x2x2mm) and smoothed (4 mm FWHM). We included motion parameters for the individual participants as an independent variable to account for noise. All events were modeled using the standard hemodynamic response function. Statistical analyses were made with specification of onsets, durations and words in the paradigm files, collected from PsychoPy. A dichotomous, independent variable of each word's concreteness level was included in the model. We included two contrasts: abstract > concrete and concrete > abstract. The experimental design was a mixed-effects design wherein all participants went through 6 separate sessions of looking at words and faces. To gain statistical power, we looked at each session as a separate entity with a fixed effect approach. This gave us more statistical power, but the results should not be extrapolated upon.

Region of interest - left Inferior frontal gyrus and left precuneus

Our hypotheses stated stronger activation of the LIFG for AW, and stronger activation in the left precuneus for CW. Given these hypotheses, we applied a region of interest (ROI) analysis using the WFU (Wake Forest University School of Medicine) pick-atlas (Maldjianet al., 2004, 2003) that referenced the AAL atlas (Tzourio-Mazoyer et al., 2002). We extracted concrete *> abstract* and *abstract > concrete* signals from all voxels in the two separate ROIs for all our scanned participants. We then made a one sample t-test to compare concrete and abstract signal change, in the two ROI, while Bonferroni-correcting for multiple comparison (Bonferroni, 1935).

Results

Behavioral analysis

Through a likelihood ratio test we established that the binary concreteness scale that we constructed from the super category from Binder et al. (2016) predicted reaction times significantly better than the null model (2 (6,2) = 24.912, $p < .0001$), see *figure 1*. We investigated all participants' reaction times by running a linear mixed effects model. The main effect of concreteness on reaction times for the faces was significant and included random intercepts for IDs and Words (Reaction time ~ Concreteness + ~1| ID / Word: $\beta = .012$, $SE = 0.0024$, $t = 4.99$, $p < .0001$), see *figure 1*. Furthermore, we investigated the main effect of concreteness, when including valence as a covariate, as abstractness seems to score high with valence (see *figure 3*). When including this covariate, the main effect of concreteness disappeared ($\beta = 0.005$, $SE = 0.004$, $t = 1.19$, $p = .24$). However, a main effect of valence was significant ($\beta = -0.017$, $SE = 0.002$, $t = -11.34$, $p > .0001$). No interaction effect occurred between the valence and concreteness of words, on the reaction time to image stimuli ($\beta = -0.002$, $SE = 0.002$, $t = -1.24$, $p = .22$) see *figure 2*.

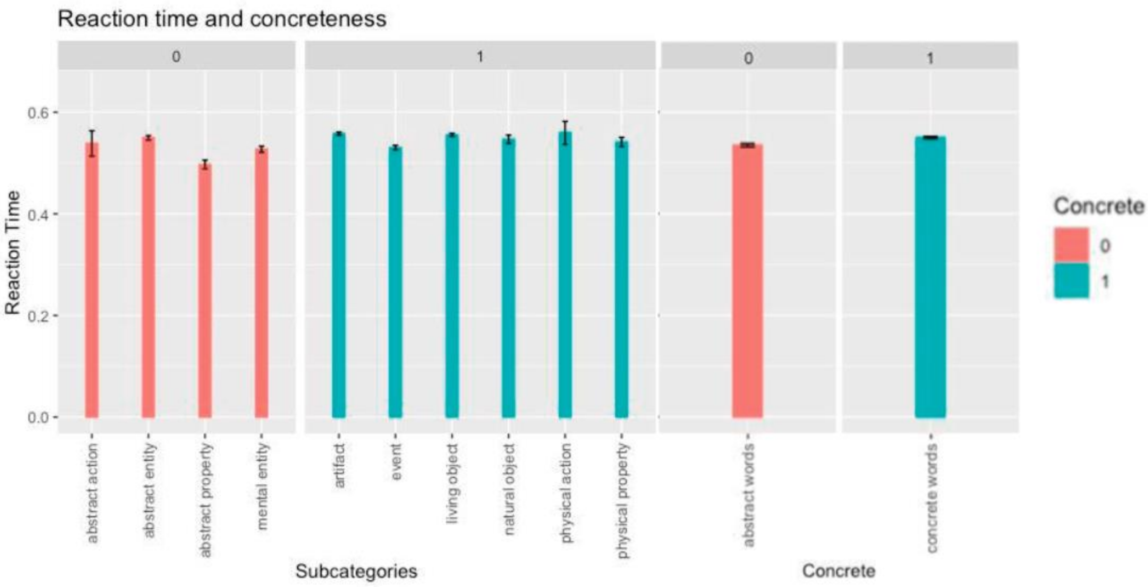

Figure 1 - Mean reaction times with standard error bars for each subcategory included in the abstract and concrete condition. Furthermore, the overall mean reaction time is plotted on the right side which displays the main effect of concreteness.

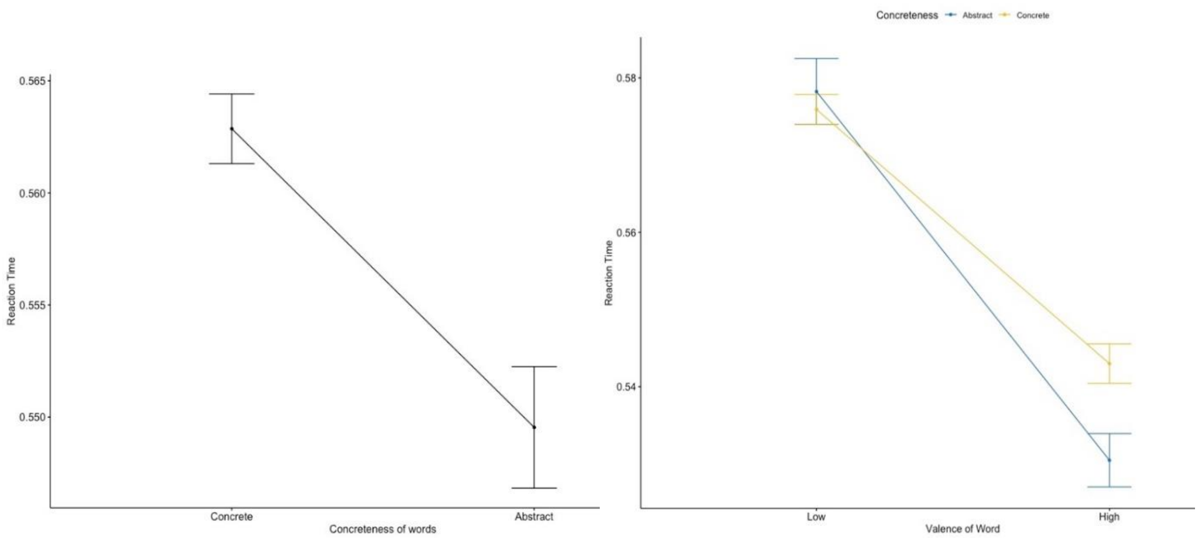

Figure 2 - The left plot displays the main effect that concreteness of the words has on reaction time. The right plot displays a bigger main effect of absolute valence on reaction time (The valence scale is dichotomized for visualization purposes).

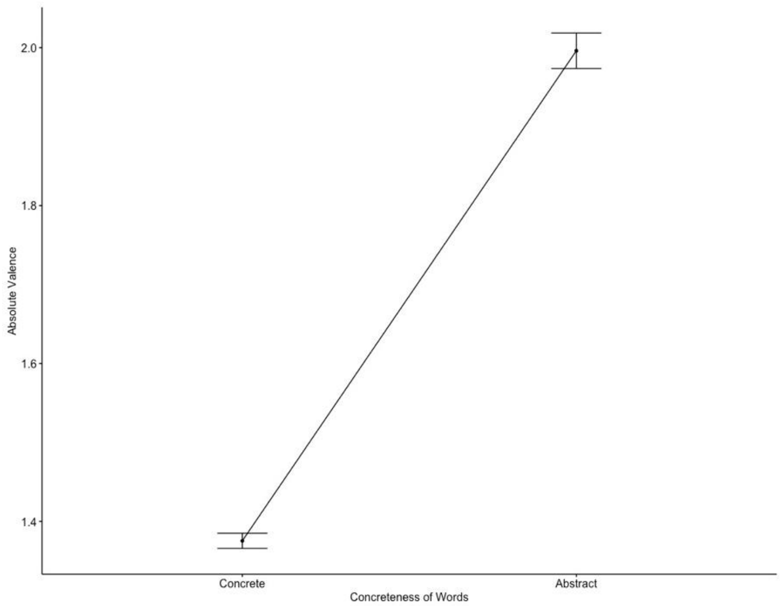

Figure 3 - Comparison of the absolute valence, from the factor analysis, to the concreteness of words.

Imaging results - Region of Interest

We approached our ROI analyses using two separate one sample t-tests in which we compared mean percentage signal-change for concrete and abstract words. When conducting the two tests, we corrected all p-values using Bonferroni's correction. The ROI analyses of the average percent signal change is shown in *table 1* and visualized in *figure 4*.

Table 1 - ROI analysis

Structure	*Contrast*	*M*	*SD*	*DF*	*T*	$P_{Bonf.corr.}$
L inf. frontal g	Abstract > concrete	0.356	1.106	53	2.366	.043
L Precuneus	Concrete > abstract	-0.130	1.050	53	-0.932	.711

Note: ROI = region of interest, M = mean, SD = standard deviation, DF = degrees of freedom, L = left, inf. = inferior, g = gyrus

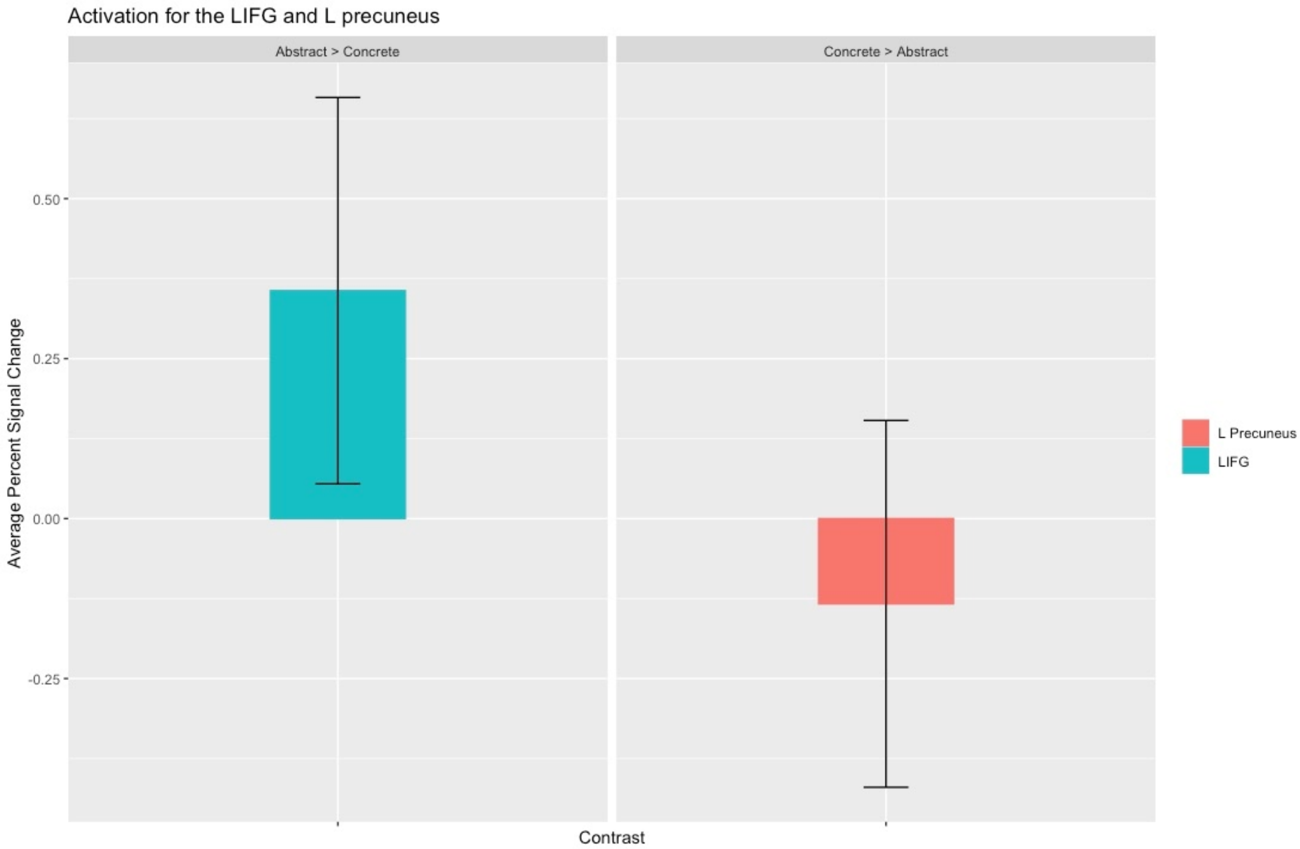

Figure 4 - Average percent signal change for the abstract > concrete contrast in the LIFG and the concrete > abstract contrast for left precuneus with 95% confidence error bars.

Whole brain analysis results

When considering the whole brain analysis rather than just the region of interest, we found three significant voxels in the contrast *abstract > concrete*. We found one voxel in the left superior temporal gyrus and two in the LIFG (see *table 2* and *figure 5*). No other voxels in any of the other contrasts were statistically significant.

Table 2 - Whole-brain analysis; Significant voxels in the abstract over concrete contrast

	Abstract > concrete				
Structure	*X*	*Y*	*Z*	*Z-score*	$P_{FWE-corr.}$
L sup. temporal g	-56	2	-6	5.18	.020
L inf. frontal g	-46	10	22	5.07	.034
L inf. frontal g	-50	20	-2	5.04	.040

Note: L = left, sup = superior, inf = inferior, g = gyrus

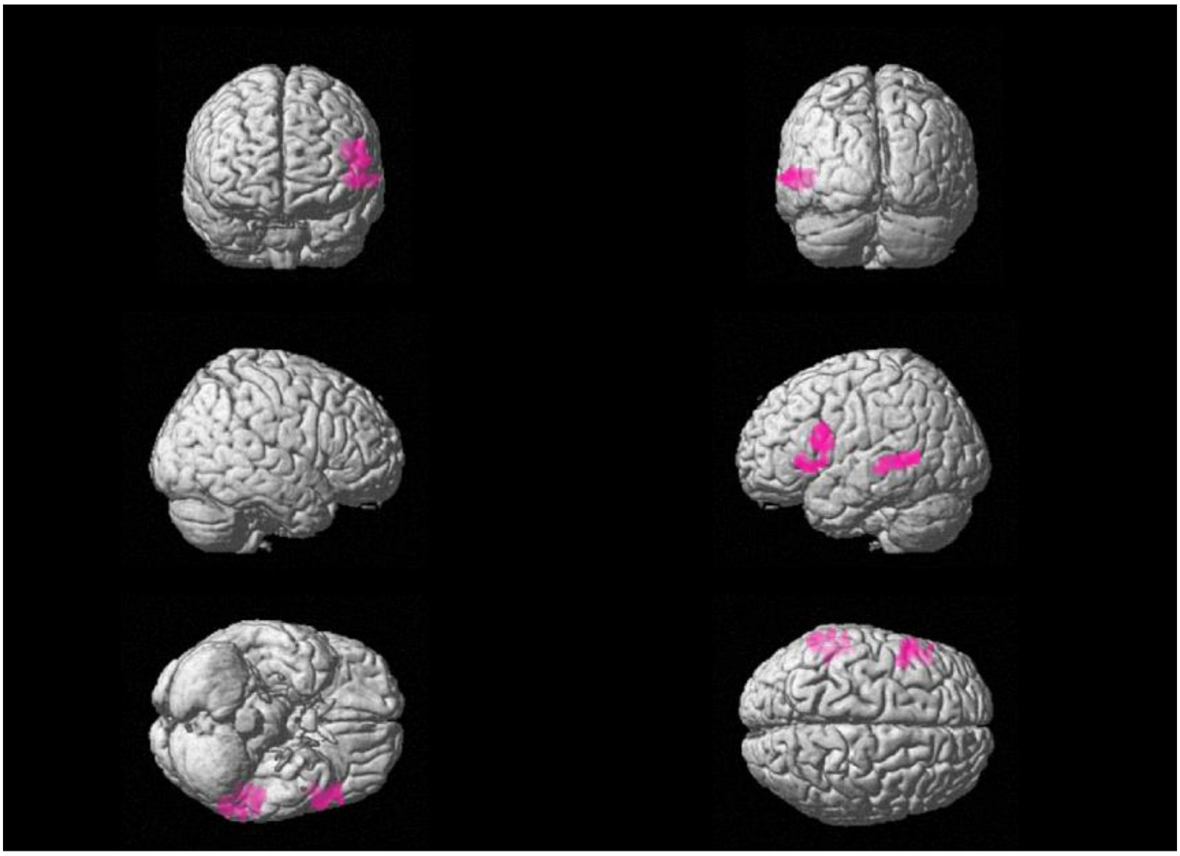

Figure 5 - Whole brain analysis for abstract > concrete, unc. p < 0.001, extent threshold at 150 voxels.

Discussion

In this study we investigated the difference in brain activity between processing abstract words (AW) and concrete words (CW), using fMRI. We found, as we hypothesized, that AW increase activity in the left inferior frontal gyrus (LIFG) compared to CW. In addition, our hypothesize stated that CW should show greater activation in the precuneus compared to AW, this hypothesis was rejected. An exploratory whole-brain analysis revealed 3 significant voxels after correcting for multiple comparison. Two voxels were found in the LIFG, and 1 in the left temporal gyrus, notably all 3 voxels were in the left hemisphere.

For our behavioral analysis we found that AW decreased reaction time on subsequent emotional image stimuli. When accounting for valence this decrease in reaction time disappeared, showing that valence was an underlying factor describing how abstractness could decrease reaction time on subsequent image stimuli. Our results support the context availability theory, because we found increased higher activation in the LIFG for AW compared to CW, and no difference in activation in the precuneus for CW compared to AW. These results indicate that CW might not be processed differently than AW because of the insignificant finding for the precuneus, which is associated with mental imagery. However, it might also be the case that the precuneus is not the right place to look for the non-verbal system proposed by the dual code theory. It could also be the case that we didn't have enough statistical power in our study to find the effect. However, the activation pattern trended slightly towards more activity in the left precuneus in AW compared to CW (see figure 4). Some researchers have argued that dual code theory and context availability theory are inadequate in explaining the concreteness effect. They highlight the fact that accounting for both imaginability and context availability there is an advantage in processing of AW compared to CW, which has been hypothesized to be related to valence, that valanced words seems to be processed faster than non-valanced words. This can also be seen in the present study, AW are usually more valanced than CW (see figure 3) (Kousta et al., 2011, Kousta et al., 2009). For an in-depth discussion see Paivio, (2013) and Vigliocco et al., (2013)

Limitations

In the present study It is important to note that due to our statistical choices our results should not be extrapolated, as mentioned in the data analysis section. Another limitation of having few participants is that we could not exclude participants that showed signs of tiredness. In the present study we did not control for our participants' handedness, which has been shown to correlate with the lateralization of the language system (Knecht et al., 2000, Szaflarski et al., 2002). The biggest limitation of this study was that the participants had their reaction time measured for recognition of image stimuli after the abstract or concrete word was presented. This limitation makes our behavioral analysis completely pointless in the discussion on how concrete and abstract words are processed independently of other external factors.

Follow up study

A follow up experiment should consider the limitations of the present study, this means including more participants, that are right-handed. Furthermore, a follow up experiment should investigate whether valence is the missing piece of the puzzle of the concreteness effect. If this is the case then AW might elicit a greater activation, in areas associated with emotional processing, compared to CW. In addition, the experiment should use a different experimental paradigm, for instance recognition of either pseudo, abstract or concrete words or retrieval of concrete or abstract words as the behavioral measures.

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Appendix

Figure 5: Emoji faces rated as happy or fearful. Left one is fearful, right one is happy.

Sensation and perception

The difference between sensation and perception is that perception is highly individual and relies on context, prior experiences, values etc. Sensation on the other hand relies solely on sensory information, which is the initial activation of our sensory organs, that receive the external stimuli and transforms it into neural activation; for instance, when light hits our rods and cones and produces electrical signals. The difference is therefore that sensation solely relies on external information, whereas perception relies on prior experiences, but also on this external information. The difference between the two concepts is most notably seen in illusions, for instance in the McGurk effect, which is an illusion where you hear a "*fa*" sound, the sensation, while watching a person saying "*ba*", many people will report that they hear the person saying "*ba*", the perception. Brain mapping has shown how different areas in the brain corresponds to the processing of different kinds of sensory information. Many of the regions are topographically organized, meaning that information that is closely related is also processed by neurons located close to one another. (Gazzaniga, Ivry, & Mangun, 2019 p. 170-200) Consider the retinotopic maps in the visual system, here adjacent points in the visual field are processed by adjacent neurons in the primary visual cortex. Tootell et al (1982) showed these retinotopic maps by injecting a radioactive tracer into monkeys. Their results can be seen in figure 1, where the visual stimulus is visible in the primary visual cortex.

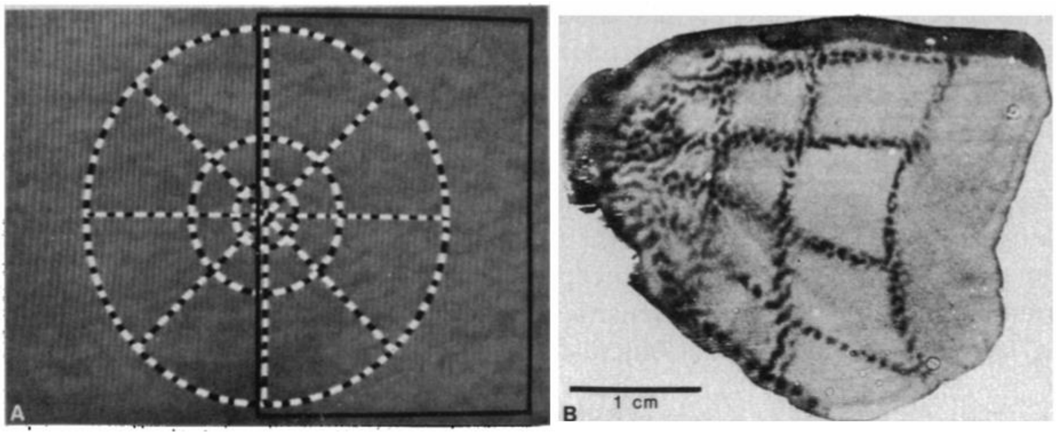

Figure 1, (A) the visual stimuli present to the monkeys in the experiment. (B) the activity pattern in the primary visual cortex after being shown the visual stimuli (A). (Tootell et al., 1982).

Multimodal perception

When describing perception, the complex interplay between different sensory modalities should be considered. This complex interplay occurs because most of our senses are stimulated simultaneously. The McGurk effect is an example of how we integrate information from different sensory modalities. The brain gives greater weight to some sensory modalities when integrating several of them, as in the McGurk effect where the sensory information from the visual modality is given more weight than the auditory (Gazzaniga, Ivry, & Mangun, 2019 p. 206). Vision is not always the dominant sense, for instance in a dark room where you can hardly see, other senses get more priority.

One intriguing neurological finding is that disturbance of one sensory system can influence another. In an experiment, by Vincenzo Romei et al (2007), the participants had to press a button when they perceived a stimulus, which was either a sound, a light or both. They applied a single pulse of transcranial magnetic stimulation (TMS) to the occipital lobe to disrupt visual processing. A single pulse of TMS has been shown to decrease performance on subsequent trials (Gazzaniga, Ivry, & Mangun, 2019 p. 91, Hallett, 2007). Reaction time for the visual trials were slower when TMS was applied, whereas reaction time for the auditory trials were decreased when TMS was applied to the occipital lobe. There are two main ways of interpreting these results, the first way is that the two systems are competing and when disrupting one the other has an easier time processing the information. The other theory is that the extra activity in the visual system induced by the TMS aids activation in the auditory system. Romei et al made a follow-up experiment investigating the two theories. They did this by utilizing the fact that applying high-intensity TMS to the occipital lobe, participants report seeing phosphenes, that is seeing light when there is none. They found the intensity where the participants reported seeing these phosphenes and took 85% of that intensity. This TMS intensity was then delivered to the participants in one of two conditions; either alone or with an auditory stimulus that came before the pulse of TMS. The results show that when the participants received the auditory stimulus, they reported an increase in the perception of phosphenes, compared to no auditory stimulus (see figure 3) (Romei et al., 2007).

These results support the hypothesis that stimuli in one sensory modality can enhance perception in another. These findings do not necessarily show, that hearing music enhances visual perception. For instance, trying to find an address, in a car, most people turn down the radio, even though they are only visually searching the environment. Studies have indicated that we do this because when concentrating on something visually, the visual cortex increases its neural response whereas the auditory cortex has its neural response decreased (Sörqvist et al., 2016). This shows that the results in the TMS study do not necessarily show that our perception is better in one modality when another modality is stimulated, that is enhanced perception might be a disadvantage in some circumstances.

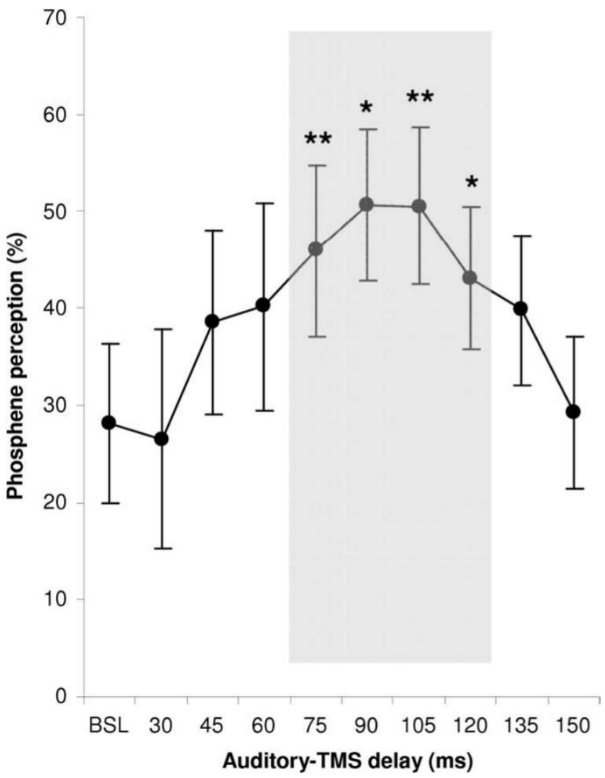

Figure 2. The relationship between the percentage of phopshene perception compared to when the single pulse TMS was introduced. 0 on the x-axis is when the sound stimulus is presented (Romei et al., 2007).

Cortical reorganization.

When perceiving stimulus, we use most of our senses, but what happens when we lose the ability to for instance see? Consider the experiment by lotfi B. Merabet et al (2008), he had half of his participants wear blindfolds for 5 days, wherein they practiced braille (a tactile writing system) for up to 6 hours a day, they also played around 2 hours of tactile games each day. The other half of the participants did the same procedure but were not blindfolded. The results showed that the blindfold group got better at tactile acuity (see figure 3a). All the participants were scanned by a functional magnetic resonance imaging (fMRI) scanner every other day, in which they did tactile tasks. The results of the fMRI data showed a blood oxygen level-dependent (BOLD) response in the visual cortex in the blindfolded group compared to the control group (see figure 3b). To determine whether this finding was purely correlational the researchers applied repeated TMS to the occipital lobe when the participants were doing a braille discrimination task. TMS in the blindfolded group impaired their accuracy (see figure 3c). On the 6th day when the blindfolds had been off for 1 day, all effects vanished. The fMRI data showed no significant BOLD response in the occipital lobe and TMS did not disturb their performance. These results show how the cortical areas can reorganize, even when the sense is not lost.

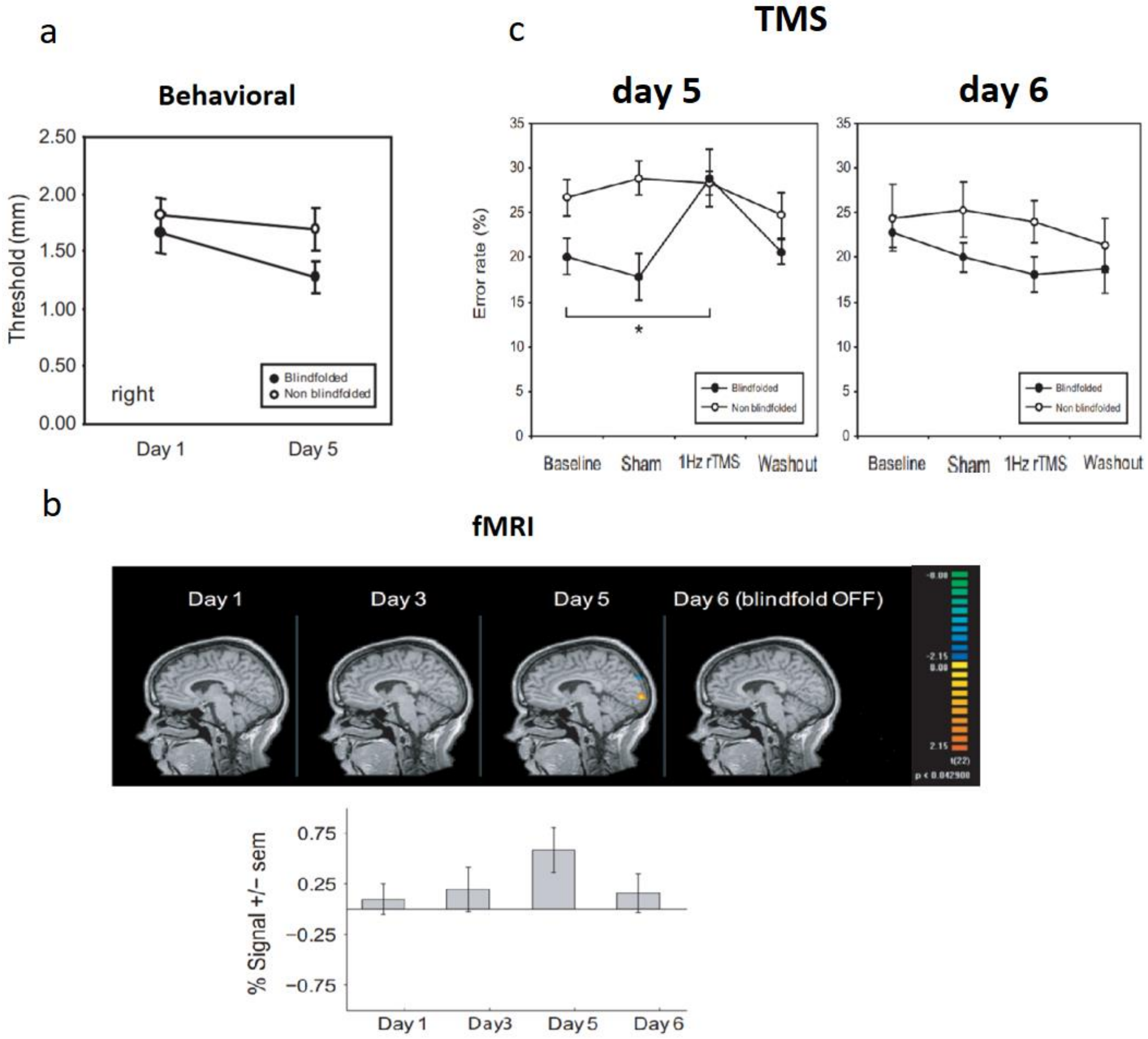

Figure 3, displays the results of the behavioral, TMS and fMRI part of lotfi B. Merabet et al (2008) experiment.
a) the blindfolded group shows better tactile acuity after 5 days.
b) shows greater BOLD responds in the visual cortex after day 5, on the 6th day when the blindfold was removed the difference disappeared.
c) shows how error rates in the blindfolded group increased when TMS was applied to the occipital lobe. The right part of figure c shows how this effect is gone on the 6th day, when the blindfolds had been removed.

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