**Representation of Abstract and Concrete Words:**

**A Functional Neuroimaging Study**

Study Group 10

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# Introduction

Behavioral research has shown repeatedly that concrete words (CW) are more easily processed than abstract words (AW). This effect is called the *concreteness effect* and relates to the findings that CW are retrieved more easily from long term memory than 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, and in 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 both a verbal and nonverbal representation, whereas AW will have to 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 can describe 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 abstract words are processed in a similar fashion, but that concrete words are easier processed because they have more associations than abstract words 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 should 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 one could argue would elicit a higher activation in the language processing area, because the VS relies solely on linguistic features, compared to CW.  
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 abstract words 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 mostly 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 180 ms or 336 ms, 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: β = .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 (β = 0.005, SE = 0.004, t = 1.19, p = .24). However, a main effect of valence was significant (β = -0.017, SE = 0.002, t = -11.34, p > .0001). No interaction effect occurred between the valence and concreteness of words (β = -0.002, SE = 0.002, t = -1.24, p = .22) see *figure 2*.

A screenshot of a cell phone

Description automatically generated

*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.*

*A screenshot of a cell phone

Description automatically generated*A close up of a map

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*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).*

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*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*.

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A screenshot of a social media post

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*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.

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A picture containing indoor, different, sitting, group

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*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 compared to CW, in addition our hypothesize stated that CW should show greater activation in the precuneus compared to AW, this hypothesis was rejected. For our behavioral analysis we found that AW decreased reaction time on subsequent emotional image stimuli, however 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 left inferior frontal gyrus 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, even though 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, highlighting 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, and as 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, this has been done with fMRI and transcranial magnetic stimulation (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 and therein consider if AW elicit a greater activation, in areas associated with emotional processing, than 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.

# Reference

* Bates, D., Maechler, M., Bolker  [aut, B., cre, Walker, S., Christensen, R. H. B., ---Singmann, H., Dai, B., Scheipl, F., Grothendieck, G., Green, P., & Fox, J. (2020). *lme4: Linear Mixed-Effects Models using ‘Eigen’ and S4* (Version 1.1-23) [Computer software]. <https://CRAN.R-project.org/package=lme4>
* Binder, J. R., Conant, L. L., Humphries, C. J., Fernandino, L., Simons, S. B., Aguilar, M., & Desai, R. H. (2016). Toward a brain-based componential semantic representation. *Cognitive Neuropsychology*, *33*(3–4), 130–174. <https://doi.org/10.1080/02643294.2016.1147426>
* Hauk, O., Johnsrude, I., & Pulvermüller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron*, *41*(2), 301–307. <https://doi.org/10.1016/s0896-6273(03)00838-9>
* Hoffman, P., Binney, R. J., & Lambon Ralph, M. A. (2015). Differing contributions of inferior prefrontal and anterior temporal cortex to concrete and abstract conceptual knowledge. *Cortex*, *63*, 250–266. <https://doi.org/10.1016/j.cortex.2014.09.001>
* Knecht, S., Dräger, B., Deppe, M., Bobe, L., Lohmann, H., Flöel, A., Ringelstein, E.-B., & Henningsen, H. (2000). Handedness and hemispheric language dominance in healthy humans. *Brain*, *123*(12), 2512–2518. <https://doi.org/10.1093/brain/123.12.2512>
* Kosslyn, S. M., Ganis, G., & Thompson, W. L. (2001). Neural foundations of imagery. *Nature Reviews Neuroscience*, *2*(9), 635–642. <https://doi.org/10.1038/35090055>
* Kousta, S.-T., Vigliocco, G., Vinson, D., Andrews, M., & Campo, E. (2011). The Representation of Abstract Words: Why Emotion Matters. *Journal of Experimental Psychology. General*, *140*, 14–34. <https://doi.org/10.1037/a0021446>
* Kousta, S.-T., Vinson, D. P., & Vigliocco, G. (2009). Emotion words, regardless of polarity, have a processing advantage over neutral words. *Cognition*, *112*(3), 473–481. <https://doi.org/10.1016/j.cognition.2009.06.007>
* Kumar, S., & P, G. (2012). MEASUREMENT OF REACTION TIME FOR PROCESSING OF CONCRETE AND ABSTRACT WORDS. *Journal of All India Institute of Speech and Hearing*, *31*.
* Kuznetsova, A., Brockhoff, P. B., Christensen, R. H. B., & Jensen, S. P. (2020). *lmerTest: Tests in Linear Mixed Effects Models* (Version 3.1-2) [Computer software]. <https://CRAN.R-project.org/package=lmerTest>
* Maldjian, J.A., Laurienti, P.J., Burdette, J.H., 2004. Precentral gyrus discrepancy in electronic versions of the Talairach atlas. Neuroimage 21, 450–455.
* Maldjian, J.A., Laurienti, P.J., Kraft, R.A., Burdette, J.H., 2003. An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets. Neuroimage 19 (3), 1233–1239.
* Mashal, N., Vishne, T., & Laor, N. (2014). The role of the precuneus in metaphor comprehension: Evidence from an fMRI study in people with schizophrenia and healthy participants. *Frontiers in Human Neuroscience*, *8*. <https://doi.org/10.3389/fnhum.2014.00818>
* Mellet, E., Tzourio-Mazoyer, N., Bricogne, S., Mazoyer, B., Kosslyn, S. M., & Denis, M. (2000). Functional anatomy of high-resolution visual mental imagery. *Journal of Cognitive Neuroscience*, *12*(1), 98–109. <https://doi.org/10.1162/08989290051137620>
* Paivio, A. (1991). Dual coding theory: Retrospect and current status. *Canadian Journal of Psychology/Revue Canadienne de Psychologie*, *45*(3), 255–287. <https://doi.org/10.1037/h0084295>
* Paivio, A. (2013). Dual coding theory, word abstractness, and emotion: A critical review of Kousta et al. (2011). *Journal of Experimental Psychology: General*, *142*(1), 282–287. <https://doi.org/10.1037/a0027004>
* psych: Procedures for Psychological, Psychometric, and Personality Research. Northwestern University, Evanston, Illinois. R package version 1.9.12, [https://CRAN.R-project.org/package=psych](https://cran.r-project.org/package=psych).
* R: A language and environment for statistical computing. R. Foundation for StatisticaComputing, Vienna, Austria. URL: https://www.R-project.org/.
* Sack, A. T., Camprodon, J. A., Pascual-Leone, A., & Goebel, R. (2005). The dynamics of interhemispheric compensatory processes in mental imagery. *Science (New York, N.Y.)*, *308*(5722), 702–704. <https://doi.org/10.1126/science.1107784>
* Szaflarski, J. P., Binder, J. R., Possing, E. T., McKiernan, K. A., Ward, B. D., & Hammeke, T. A. (2002). Language lateralization in left-handed and ambidextrous people: FMRI data. *Neurology*, *59*(2), 238–244. <https://doi.org/10.1212/wnl.59.2.238>
* Tzourio-Mazoyer, N., Landeau, B., Papathanassiou, D., Crivello, F., Etard, O., Delcroix, N., Mazoyer, B., Joliot, M., 2002. Automated anatomical labelling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain. Neuroimage 15 (1), 273–289
* Vigliocco, G., Kousta, S., Vinson, D., Andrews, M., & Del Campo, E. (2013). The representation of abstract words: What matters? Reply to Paivio’s (2013) comment on Kousta et al. (2011). *Journal of Experimental Psychology. General*, *142*(1), 288–291. <https://doi.org/10.1037/a0028749>
* Wang, J., Conder, J. A., Blitzer, D. N., & Shinkareva, S. V. (n.d.). *r Human Brain Mapping 31:1459–1468 (2010) r Neural Representation of Abstract and Concrete Concepts: A Meta-Analysis of Neuroimaging*.
* Yui, L., Ng, R., & Perera-W.A., H. (2017). *Concrete vs abstract words – what do you recall better? A study on dual coding theory* [Preprint]. PeerJ Preprints. <https://doi.org/10.7287/peerj.preprints.2719v1>

# Appendix

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