Revision of XGE-2019-2286 as invited by the action editor, Julie Van Dyke, PhD.

The concreteness advantage in lexical decision does not depend on perceptual simulations

Roberto Bottini[1,2], Piermatteo Morucci[3], Anna D'Urso[1,2], Olivier Collignon[4,1],
Davide Crepaldi[2]

1. Centre for Mind/Brain Sciences, University of Trento, Italy
2. International School for Advanced Studies (SISSA), Trieste, Italy
3. Basque Center on Cognition Brain and Language (BCBL), University of the Basque Country UPV/EHU
4. Institute of Psychology (IPSY) and Institute of Neuroscience (IONS), University of Louvain, Belgium

Word count

Abstract: 212

Main text: 2955

*Corresponding Author:

Roberto Bottini, Ph.D.

CIMeC - Center for Mind/Brain Sciences, University of Trento

Via delle Regole 101, 38123, Mattarello (TN), Italy.

Phone: +390461283010

roberto.bottini@unitn.it

Abstract

Abstract words are typically more difficult to identify than concrete words in lexical decision, word naming and recall tasks. This behavioral advantage, known as *concreteness effect*, is often considered as evidence for embodied semantics, which emphasizes the role of sensorimotor experience in the comprehension of word meaning. Under this view, on-line sensorimotor simulations triggered by concrete words, but not by abstract words, facilitate the access to words meaning and speed up word identification. To test whether perceptual simulation is the driving force underlying the concreteness effect, we compared data from early blind and sighted individuals performing an auditory lexical decision task. Subjects were presented with property words referring to abstract (e.g. *logic*), concrete multimodal (e.g. *spherical*) and concrete unimodal visual concepts (e.g. *blue*). According to the embodied account, the processing advantage for concrete unimodal visual words should disappear in the early blind, as they cannot rely on visual experience and simulation during semantics processing (i.e. purely visual words should be abstract for early blind people). On the contrary, we found that both sighted and blind individuals are faster when processing multimodal and unimodal visual words compared to abstract words. This result suggests that the concreteness effect does not depend on perceptual simulations but might be driven by modality-independent properties of word meaning.

Keywords: Concreteness effect, Blindness, Embodied Semantics, Lexical processing.

Introduction

Concrete words are typically processed more quickly and accurately than abstract words in lexical decision, word naming and recall task (Allen & Hulme, 2006; Fliessbach, Weis, Klaver, Elger, & Weber, 2006; Groot, 1989; Kroll & Merves, 1986; Schwanenflugel, Harnishfeger, & Stowe, 1988; Schwanenflugel & Stowe, 1989). Why do words that refer to tangible entities such as *cat* or *iron* beneficiate this processing advantage compared to abstract terms such as *freedom* or *truth*?

One set of theories suggests that the concreteness effect is not related to concreteness itself, but to other properties that correlate with it. For instance it has been proposed that concrete words are learned earlier in life (Brown & Watson, 1987) and easier to contextualize (Schwanenflugel et al., 1988), thus faster to recall and recognize. Alternatively, ease of processing may be a direct consequence of the perceptual bases of concrete concepts: Words that refer to tangible things may activate perceptual knowledge that is not readily available for abstract concepts (Connell & Lynott, 2012; Paivio, 1986). According to this approach, retrieving conceptual knowledge (e.g., the concept of RED) consists, at least in part, in re-activating sensory-motor processes related to the experience of conceptual referents (e.g., perceiving a red object). Different theories tend to disagree on the precise nature of the representational units that constitute such a modality-specific system. For instance, the Dual-Coding Theory (DCT) refers to *imagens*, representational units that give rise to conscious imagery when activated (Paivio, 1986); whereas Embodied Semantics (ES) refers to *sensorimotor simulations*, meaning unconscious and automatic reenactments of experience that should be distinguished from mental imagery (Connell & Lynott, 2010, 2012, 2014, 2016; Dudschig, de la Vega, De Filippis, & Kaup, 2014; Lachmair, Dudschig, De Filippis, de la Vega, & Kaup, 2011). The nature of abstract concepts and the precise mechanism behind the concreteness effect may also differ between theories. In DCT both abstract and concrete concepts can be represented through a verbal code, and the fact that only concrete concepts can activate both codes (verbal and sensorimotor) gives them a processing advantage (Paivio, 1986). In embodied semantics verbal representations play a rather marginal role (but see, Andrews, Vigliocco, & Vinson, 2009) and abstract concepts can be represented via (more complex) simulations, such as situational models (Zwaan, 2016), relational schemas (Barsalou, Dutriaux, & Scheepers, 2018) or multimodal abstractions (Barsalou, 2016; Binder, 2016), to name a few. Thus, if abstract concepts, as well, are ultimately based on simulations (Connell & Lynott, 2012), it follows that strongly perceptual words such as *table*, *music* or *red*, which refer to a ″relatively simple and discrete package of perceptual information″ (Connell & Lynott, 2012; p. 463) are easier to simulate and faster to process.

The embodied account of the concreteness effect is supported by findings showing that facilitation in word naming and lexical decision tasks is well predicted by the perceptual strength of the word referent (Connell & Lynott, 2012). Lynott and Connell (Lynott & Connell, 2013) collected ratings of perceptual strength for several words by asking participants how much they experience a particular object (e.g., chair) or property (e.g., red) using each of the five different senses. For instance, the property of being "red" will have high strength in sight, but low strength in the other senses. On the other hand, the property of being "wet" will have a high strength in touch, but also sight, maybe some strength in taste, and very little strength in smell and audition (see Fig.1). From these norms it is easy to extract Maximal Perceptual Strength (MPS), as the strength in the dominant perceptual modality, and use this figure as a predictor of behavioral performances. MPS revealed itself to be a strong predictor of reaction times and accuracy in both word naming and lexical decision tasks. Interestingly, MPS ratings outperformed even the classic ratings of concreteness and imageability, suggesting that automatic and unconscious simulations (Connell & Lynott, 2016) may explain the concreteness advantage better than the activation of a mental imagery code (Paivio, 1986).

In this experiment, we tested *causally* the idea that automatic on-line sensorimotor simulations are the driving factor behind the concreteness effect by comparing sighted and early blind individuals who lost sight completely at birth or very early in life (<3 years old). The rationale behind the study is that early lack of vision will prevent to associate unimodal visual words (e.g., “red”, “transparent”, “multicolor”) with a simple and discrete package of sensorimotor simulations, making them more similar to abstract words. Previous neuroimaging studies have shown that the meaning of strongly visual words such as colors is represented in the anterior temporal lobe (ATL) in both sighted and blind, whereas only in sighted a similar activation was found also in color-related visual regions (V4 complex; cite; cite). This result confirms the lack of visual sensory simulations in the blind, although the meaning of visual word is still represented in the ATL independently of visual experience. One may argue, however, that blind people may simulate the meaning of visual words by associating them with some related (non visual) sensory experience (e.g., red might remind a rose), and thus differentiating them from abstract words on the basis of sensorimotor simulations (arguably, in sensorimotor brain regions). However, this mechanism would not be so different from the multimodal experience that can be indirectly associated with other abstract words (e.g., love might remind a rose) and, perhaps more convincingly, another fMRI study that compared directly abstract and visual words in congenitally blind people found that these two types of semantic knowledge showed a similar neural profile (activating overlapping regions in the ATL) with no additional sensorimotor activation related to visual words (Striem-Amit, Wang, Bi, & Caramazza, 2018).

In our experiment participants engaged in a lexical decision task that included abstract words (denoting non-tangible properties; e.g., *true*), concrete multimodal words (denoting properties that can be perceived with several senses and can be perceived also by blind people; e.g., *hard*), and concrete visual words (denoting properties that can only be perceived via sight and are perceptually inaccessible to blind people; e.g., *red*). The prediction was straightforward: if the concreteness effect is based on sensorimotor simulations, the processing advantage for visual words (compared to abstract words) should disappear or be significantly reduced in blind people.

Method

Participants. 42 volunteers (21 early blind, EB; 21 sighted controls, SC) were recruited for the experiment in exchange for payment. They were all Italian native speakers with no reported auditory disabilities. The sample size was taken based on a pilot study with sighted people only, with the same number of participants, showing a reliable concreteness effect (see supplementary materials). Given that, in the pilot study, the observed power to detect the concreteness effect was 99.70% (computed with the simr package; Green & Macleod, 2016), indicating very high power, we chose to conduct the current experiment with the same number of participants. EB and SC (see Table 1) were matched pairwise for gender, age, and years of formal education. All the EB participants lost their sight completely at birth or before the age of three and reported no visual memories. All participants were blindfolded during the experiment. The ethics committee of the University of Trento approved this study (Prot. 2017-020), and participants gave their informed consent before participation.

Table 1. Early Blind (EB) and Sighted Control (SC) participant information.

Early Blind	**Age**	**Gender**	**Scolarity**	**Age onset blindness**	**Etiology**	**Sighted Control**	**Age**	**Gender**	**Scolarity**
EB_01	54	F	13	0	Congenital renitis pigmentosa	SC_01	51	F	13
EB_02	46	F	13	0	Bilateral congenital microftalmia	SC_02	48	F	13
EB_03	30	F	13	0	Retinopathy of prematurity (ROP)	SC_03	32	F	18
EB_04	38	M	13	0	ROP	SC_04	39	M	13
EB_05	58	F	8	0	ROP	SC_05	59	F	8
EB_06	44	F	13	0	ROP/ Retrolentar fibroplasia	SC_06	43	F	13
EB_07	27	M	11	0	Peters’ congenital glaucoma	SC_07	27	M	13
EB_08	30	F	13	0	ROP	SC_08	25	F	16
EB_09	29	M	13	3	Premature birth/Retinal detachment	SC_09	27	M	13
EB_10	41	M	13	0	Unknown (problems during pregnancy)	SC_10	39	M	13
EB_11	47	M	8	0	Congenital glaucoma	SC_11	46	M	13
EB_12	39	F	11	0	ROP	SC_12	38	F	13
EB_13	39	F	13	0	ROP	SC_13	41	F	13
EB_14	45	M	18	0	Optic nerve atrophy	SC_14	44	M	18
EB_15	35	F	16	0	Leber's congenital amaurosis	SC_15	39	F	16
EB_16	21	F	13	0	Leber's congenital amaurosis	SC_16	20	F	13
EB_17	36	F	13	0	ROP	SC_17	33	F	13
EB_18	53	F	18	2	Retinoblastoma	SC_18	52	F	16
EB_19	36	F	18	0	Bilateral congenital microftalmia	SC_19	32	F	16
EB_20	29	F	13	2	Retinoblastoma	SC_20	26	F	13
EB_21	30	M	13	0	Renitis pigmentosa	SC_21	35	M	16
M	38.43		13.19			**M**	37.90		13.95
SD	9.74		2.66			**SD**	10.07		2.25

Note. L = left-handed; R = right-handed; A = ambidextrous

Stimuli and apparatus. Forty abstract (e.g., *inconscio* “unconscious”, *puro* “pure”), 40 concrete multimodal (e.g., *cremoso* “creamy”, *fresco* “fresh”) and 40 concrete unimodal visual words (e.g., *rosso* “red”, *abbagliante* “dazzling”) were selected from an Italian database of modality exclusivity norms (Morucci, Bottini, & Crepaldi, 2019). Following Connell and Lynott (2012), we used Maximum Perceptual Strength to distinguish between abstract and concrete items. The list of abstract words includes items with low values of maximum perceptual strength (M= 2.88, SD= 0.63), whereas concrete multimodal (M= 4.77, SD= 0.28) and concrete visual (M= 4.91, SD= 0.11) words were very high in maximum perceptual strength. In order to distinguish between concrete visual and multimodal words, we relied on the modality exclusivity score proposed by Connell & Lynott, 2012: concrete visual unimodal words had overall very high values in modality exclusivity (M=0.83, SD=0.1, on a 0–1 scale) compared to concrete multimodal words (M=0.39, SD=0.08), and their dominant modality was always vision (see Table 2). Overall values for frequency, number of syllables, length in phonemes, and familiarity were kept extremely similar across the three conditions (see Table 2). The familiarity ratings came from the Italian database of modality exclusivity norms (Morucci et al., 2019), and were based on the judgment of sighted individuals. However, we also collected familiarity ratings on the stimuli used in this experiment from both sighted and blind participants, after they performed the experiment. Control analysis (reported in the supplementary materials, S2) showed that familiarity ratings between sighted and blind were highly correlated ($r > .88$) and that adding this figure to the regression model leaves the results unchanged.

It is well known that spoken words may be in some cases recognized before the end of the word, more precisely at their "uniqueness point" (Marslen-wilson, 1987), the point in time when the acoustic and phonetic information already presented (e.g., the syllables "ba"-"na") is compatible with a single lexical entry (i.e., banana). Thus, we aligned our RT analysis to the uniqueness point (UP) of each word. Because Italian lacks a sufficiently-sized database for phonological word forms, and because it features a near-perfect phoneme-to-grapheme correspondence, we computed the UP for each word based on an orthographic database (e.g., SUBTLEX–IT, 130M tokens; Crepaldi et al., 2015). First, we divided the duration of each stimulus (auditory waveform) by the number of graphemes that constitute it; Then we multiplied this result by the orthographic UP (position in number of graphemes) calculated comparing each wordform with other wordforms in the database (see also Vignali et al., 2020 for a similar procedure).

For each word, we created a corresponding pseudoword using the software Wuggy (Keuleers & Brysbaert, 2010). Pseudowords were matched (pairwise) to real words stimuli for number of syllables, word length, number of letters and stress pattern. Words and pseudowords were then synthesized with an artificial female voice (TalkToMe software) and recorded using Audio Hijack Pro in a single wave file including all the lexical items (recording format: 16 bits, sample frequency of 44.1 kHz). Individual items were then selected and saved as separate wave files. Finally, the amplitude of each audio file was normalized and the silence before and after the spoken word was cut using the software Praat (Boersma & Weenink, 2018). The original audio files can be examined at [https://osf.io/5gtjw/?view_only=5e029ca40c6d4628aac4ff7b2692b623].

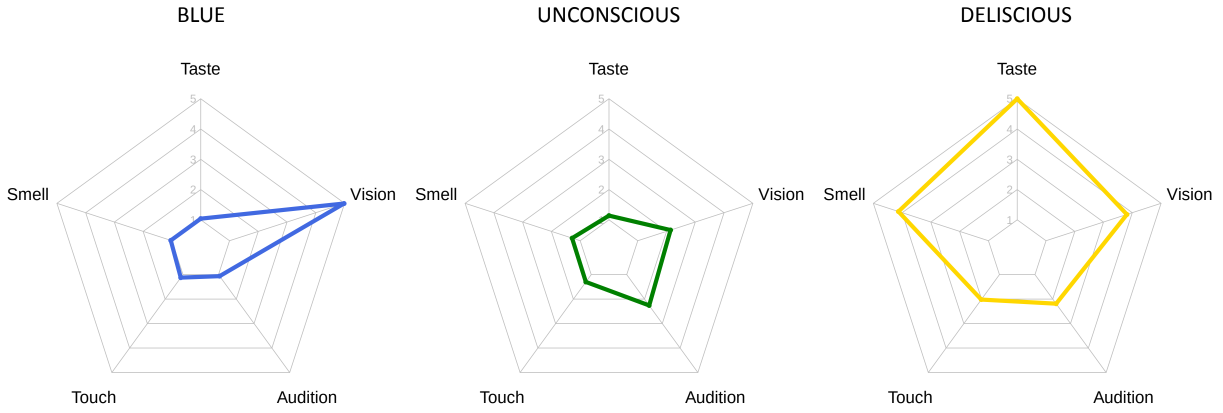
Table 2

Psycholinguistic Variables Matched Across Semantic Type

	Abstract	Multimodal	Visual
N. Syllables	3.43 (0.81)	3.38 (0.87)	3.38 (0.98)
N. Phonemes	7.75 (2.08)	7.90 (2.17)	8.10 (2.33)
Frequency (zipf)	2.99 (0.98)	2.93 (0.83)	2.93 (0.98)
Familiarity (1-7)	5.51 (1.19)	5.44 (1.07)	5.39 (1.21)

Values in parenthesis indicate the standard deviation.

Procedure. Stimuli were presented to participants via headphone using MatLab Psychtoolbox (Brainard, 1997; Pelli, 1997). The inter-trial interval varied randomly from 1500 to 2500 ms and subjects were asked to decide as quickly and as accurately as possible whether the stimulus was a word by pressing one of two response keys. Positive (“Yes”) responses were always associated with the participants′ dominant hand. After each word, participants had 3 seconds to respond. After this time window, a warning sound notified the subject if no button was pressed. The full set of stimuli was played two times, for a total of 480 stimuli randomly presented in 6 experimental blocks. At the end of each block a short break followed. Before starting the experiment, subjects performed a familiarization task with 30 practice trials. Stimuli were presented in a random order, and the sequence was randomized anew for each subject. Data and analysis scripts are available at https://osf.io/5gtjw (Bottini et al., 2019).



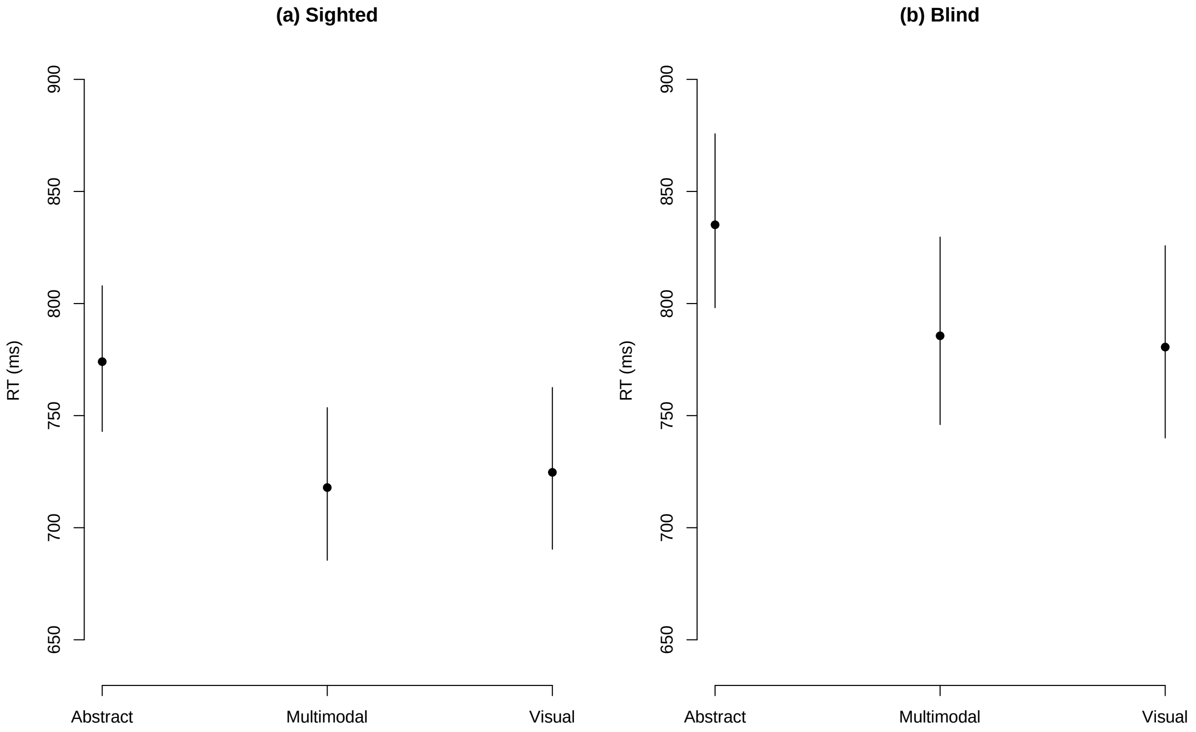
BLUE UNCONSCIOUS DELISCIOUS

Figure 1. Spider plots representing the typical perceptual profile of a unimodal visual word (“blue”, left panel), an abstract word (“unconscious”, central panel), and a multimodal word (“delicious”, right panel).

Results

We first analyze the overall accuracy at the subject and item level, looking for outliers. In the blind group, one subject was excluded because of low accuracy, showing an error rate that was more than 2.5 SD higher than the other blind participants. We did not find outliers in the sighted group. At the item level we excluded three words that showed an accuracy rate 2.5 SD lower than the average rate in both sighted and blind. These three words were all abstract words, and this result could be due, at least in part, to the same mechanisms underlying the concreteness effect. However, to avoid the possibility that the expected concreteness effect could be driven by these few outlier words, we decided to exclude them from the analysis[1].

The average accuracy in the lexical decision task was very high: 98% in both the sighted and the blind group. Both in sighted and in blind participants, accuracy was slightly lower for abstract words (SC= 98%; EB=97%), compared to concrete visual (SC= 99%; EB=99%) and multimodal (SC= 99%; EB=98%) words. However, not surprisingly, participants were clearly at ceiling here; thus, we focused on the analysis of the reaction times.



---

[1] However, results do not change if these three words are included in the analysis.

Figure 2 Results of Experiment 1. RTs model estimates for sighted and blind people across the three different semantic types. Error bars represent 95% confidence intervals (Fox & Weisberg 2018).

We removed from the analysis all the inaccurate trials (1.75%), plus a few datapoints with RT responses lower than 300ms (0.02%). RTs were calculated from the uniqueness point of each word (see Method section)[2]. A linear transformation was applied by adding the mean of the uniqueness points to all trials in order to avoid negative values in the few cases (10% of the datapoints) when subjects replied slightly before the UP. RTs were then trimmed by excluding latencies that were 3 SD larger or smaller than the mean RT of each subject (1.3% of datapoints), inverse transformed to approach normality and analyzed using a linear mixed effect regression through the package lme4 (Bates, Machler, Bolker, & Walker, 2014) in R (R Core Team, 2013).[3] Semantic Type (abstract, multimodal, visual), Group (EB, SC) and the interaction between Semantic Type and Group were entered as fixed effects. The subject intercept and slopes were entered as random effects. We report the Bayes Factor (Morey, Rouder, & Jamil, 2018) for the interaction effect, in order to account for the potential lack of a difference between groups.

Results (see Fig. 2) showed a main effect of Group (Chisq(1)= 5.70, p= 0.02), and Semantic Type (Chisq(2)= 127.51, p< 0.001). The Semantic Type by Group interaction, instead, did not reach the significance threshold (Chisq(2)= 3.66, p= 0.16), and showed a very small Bayes Factor (BF = 0.012), indicating a negligible effect of the interaction term: the effect of Semantic Type is not statistically different in sighted and blind participants.

---

[2] We also performed control analysis calculating RTs from the word onset and the results did not change (see supplementary material, S3).

[3] Results do not change when raw RTs are considered (including negative ones) and neither trimming nor transformation is applied: Main effect of Group (Chisq(1)= 4.81, p= 0.03), Semantic Type (Chisq(2)= 145.93, p< 0.001), Semantic Type by Group interaction (Chisq(2)= 4.37, p= 0.11).

To clarify the pattern of results, we unpacked the overall main effect of Semantic Type via post-hoc pairwise comparisons. Critically for our predictions, abstract words elicited slower response times than visual (Semantic Type: Chisq(1)= 102.76, $p< 0.001$) and multimodal words (Semantic Type: Chisq(1)= 129.72, $p< 0.001$), in line with a concreteness advantage. On the other hand, there was no significant difference between visual and multimodal words (Semantic Type: Chisq(1)= 0.14, $p= 0.71$).

Discussion

In this study we tested whether the concreteness effect in lexical decision tasks is driven by on-line sensorimotor simulations. We found that blind people processed concrete words faster than abstract words, exactly like their sighted counterpart. Crucially, this was true also for visual unimodal words: Concrete words that refer to object properties that can be experienced only with sight (e.g., red). If the processing advantage of concrete words was due to on-line sensorimotor simulation, blind people (who cannot simulate vision) should show a reduced or null concreteness effect. This would be in line with the fact that, for blind people, colors and other highly-visual concepts are not learned via sensorimotor experience and are considered abstract (although they are still intelligible, as for sighted people abstract concepts such as “quark” or “unconscious” are intelligible; Striem-Amit, Wang, Bi, & Caramazza, 2018). Instead, we found that visual words benefited the same processing advantage in both sighted and blind, suggesting that sensorimotor simulations are not necessary to drive the concreteness effect. Is it possible that the concreteness is effect is driven by on-line simulations in the sighted but not in the blind? We consider this unlikely. For instance, a previous study using a causal manipulation have shown that visual noise does not interfere with the concreteness effect during lexical decision in sighted people (Ostarek & Huettig, 2017), as a simulationist account would predict. This result, together with our current study, suggest that the concreteness advantage during lexical decision does not depend on sensorimotor simulations. Interestingly, though, visual noise did interfere with the concreteness advantage when subjects were asked to make an explicit judgment on the concreteness of words (instead of a lexical decision; Ostarek & Huettig, 2017). Similarly, a recent high-powered study (N=205; Davis, Joergensen, Boddy, Dowling, & Yee, 2020) showed that animacy judgment on words (i.e., an explicit semantic judgment) was disrupted by a concurrent visual task depending on the visual perceptual strength associated with the words' referent. In another fMRI study, visual regions of the brain crucial for perceiving objects shape, were active during conceptual retrieval only when a shape-related judgment was required (e.g., Is a banana elongated?), but not with a semantically orthogonal task (e.g., Is a banana a fruit? Martin, Douglas, Newsome, Man, & Barense, 2018). Accordingly, there is evidence that differences between sighted and blind in processing color concepts emerge when an explicit color-related processing is required, both at the behavioral (Connolly, Gleitman, & Thompson-Schill, 2007; Kim, Elli, & Bedny, 2019) and the neural level (Bottini et al., 2020; Wang, Men, Gao, Caramazza, & Bi, 2020).

This series of results allows us to situate our study in the broader debate about the role of modality-specific simulations in conceptual processing (Ostarek & Bottini, 2021). The lack of difference between sighted and blind in our lexical decision task is in line with the hypothesis that the recruitment of early visual areas during language processing is not automatic, but depends on processing demands (Bottini, Bucur, & Crepaldi, 2016; Ostarek & Huettig, 2017; but see Lewis & Poeppel, 2014). Our results suggest that the concreteness advantage emerging during word recognition and reported in several experiments is not due to on-line sensorimotor simulations; yet, sensorimotor simulations seem to play a functional role in conceptual processing in other contexts, especially (but not exclusively) when task demands requires an explicit recall of perceptual knowledge (Ostarek & Huettig, 2017; Ostarek, Joosen, Ishag, de Nijs, & Huettig, 2019).

If perceptual simulations are not automatically accessed during language processing, what exactly does make concrete words easier to process, even in a lexical decision task? Several variables, known to influence word processing time, are correlated with concreteness. Among them, there are semantic variables such as contextual availability (Schwanenflugel et al., 1988; Schwanenflugel & Stowe, 1989), Age of Acquisition (Brown & Watson, 1987), Semantic Neighborhood Density (Reilly & Desai, 2017), as well as formal aspects such as the phonological and morphological structure of words (Reilly, Hung, & Westbury, 2017; Reilly & Kean, 2007). It is possible that some of these variables are partly dependent on the perceptual origin of concepts (e.g., concrete words are learned earlier in life), although this does not necessarily entail the activation of sensorimotor simulations during word processing.

Context of the research

This paper is part of a broader research program that aims to clarify the role of sensorimotor simulations in cognition using early blind individuals as a model. Together with behavioral studies like the current one, the research include neuroimaging studies already published (Bottini et al., 2020) or in preparation. We think that the study of visual knowledge in early blind individuals constitute a privileged model system to investigate the causal role of simulations (Ostarek & Bottini, 2021) as well as the neural architectures involved in conceptual processing and their flexibility (Bottini et al., 2020; Mattioni et al., 2020).

Acknowledgements

This research was supported in part by the PRIN grant “How do we make sense of words” (Project: grant n. 2015PCNJ5F) awarded to D.C. and O.C. by the Italian Ministery of Education; the ERC grant MADVIS – Mapping the Deprived Visual System: Cracking function for Prediction (Project: 337573, ERC-20130StG) and the Belgian Excellence of Science (EOS) program (Project No. 30991544) awarded to O.C. We thank Marco Barilari for assistance in running the experiment. O.C. is a research associate at the Fond National de la Recherche Scientifique de Belgique.

Data availability: data and analysis scripts are available at https://osf.io/5gtjw

References

Allen, R., & Hulme, C. (2006). Speech and language processing mechanisms in verbal serial recall. *Journal of Memory and Language*, *55*, 64–88. https://doi.org/10.1016/j.jml.2006.02.002

Andrews, M., Vigliocco, G., & Vinson, D. (2009). Integrating experiential and distributional data to learn semantic representations. *Psychological Review*, *116*(3), 463–498. https://doi.org/10.1037/a0016261

Barsalou, L. W. (2016). On Staying Grounded and Avoiding Quixotic Dead Ends. *Psychonomic Bulletin & Review*, *23*(4), 1122–1142. https://doi.org/10.3758/s13423-016-1028-3

Barsalou, L. W., Dutriaux, L., & Scheepers, C. (2018). Moving beyond the distinction between concrete and abstract concepts. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2014). Fitting Linear Mixed-Effects Models using lme4. *Eprint ArXiv:1406.5823*, 51. https://doi.org/10.18637/jss.v067.i01

Binder, J. R. (2016). In defense of abstract conceptual representations. *Psychonomic Bulletin & Review*, *23*(4), 1096–1108. https://doi.org/10.3758/s13423-015-0909-1

Boersma, P., & Weenink, D. (2018). Praat: doing phonetics by computer. Retrieved from http://www.praat.org/

Bottini, R., Bucur, M., & Crepaldi, D. (2016). The nature of semantic priming by subliminal spatial words. Embodied or disembodied? *Journal of Experimental Psychology: General*, *145*(9), 1160–1176. https://doi.org/10.1037/xge0000197

Bottini, R., Ferraro, S., Nigri, A., Cuccarini, V., Bruzzone, M. G., & Collignon, O. (2020). Brain Regions Involved in Conceptual Retrieval in Sighted and Blind People. *Journal of*

Cognitive Neuroscience, 1–17. https://doi.org/10.1162/jocn_a_01538

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, *10*, 433–436. https://doi.org/10.1163/156856897X00357

Brown, G. D. A., & Watson, F. L. (1987). First in , first out : Word learning age and spoken word frequency as predictors of word familiarity and word naming latency. *Memory & Cognition*, *15*(3), 208–216.

Connell, L., & Lynott, D. (2010). Look but don’t touch: Tactile disadvantage in processing modality-specific words. *Cognition*, *115*(1), 1–9. https://doi.org/10.1016/j.cognition.2009.10.005

Connell, L., & Lynott, D. (2012). Strength of perceptual experience predicts word processing performance better than concreteness or imageability. *Cognition*, *125*(3), 452–465. https://doi.org/10.1016/j.cognition.2012.07.010

Connell, L., & Lynott, D. (2014). I see/hear what you mean: Semantic activation in visual word recognition depends on perceptual attention. *Journal of Experimental Psychology: General*, *143*(2), 527–533. https://doi.org/10.1037/a0034626

Connell, L., & Lynott, D. (2016). Do We Know What We’re Simulating ?Information Loss on Conscious Imagery.

Connolly, A. C., Gleitman, L. R., & Thompson-Schill, S. L. (2007). Effect of congenital blindness on the semantic representation of some everyday concepts. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(20), 8241–8246. https://doi.org/10.1073/pnas.0702812104

Crepaldi, D., Amenta, S., Pawel, M., Keuleers, E., & Brysbaert, M. (2015). SUBTLEX-IT. Subtitle-based word frequency estimates for Italian. In *Proceedings of the Annual Meeting* *of the Italian Association For Experimental Psychology* (pp. 10–12).

Davis, C. P., Joergensen, G. H., Boddy, P., Dowling, C., & Yee, E. (2020). Making It Harder to "See" Meaning: The More You See Something, the More Its Conceptual Representation Is Susceptible to Visual Interference. *Psychological Science*, *31*(5), 505–517. https://doi.org/10.1177/0956797620910748

Dudschig, C., de la Vega, I., De Filippis, M., & Kaup, B. (2014). Language and vertical space: On the automaticity of language action interconnections. *Cortex*, *58*, 151–160. https://doi.org/10.1016/j.cortex.2014.06.003

Fliessbach, K., Weis, S., Klaver, P., Elger, C. E., & Weber, B. (2006). The effect of word concreteness on recognition memory. *NeuroImage*, *32*, 1413–1421. https://doi.org/10.1016/j.neuroimage.2006.06.007

Green, P., & Macleod, C. J. (2016). SIMR: An R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution*, *7*(4), 493–498. https://doi.org/10.1111/2041-210X.12504

Groot, A. M. B. De. (1989). Representational Aspects of Word Imageability and Word Frequency as Assessed Through Word Association. *Journal of Experimental Psychology : Learning , Memory , and Cognition*, *15*(5), 824–845.

Keuleers, E., & Brysbaert, M. (2010). Wuggy : A multilingual pseudoword generator. *Behavior Research Methods*, *42*(3), 627–633. https://doi.org/10.3758/BRM.42.3.627

Kim, J. S., Elli, G. V, & Bedny, M. (2019). Knowledge of animal appearance among sighted and blind adults. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(23), 11213–11222. https://doi.org/10.1073/pnas.1900952116

Kroll, J. F., & Merves, J. S. (1986). Lexical Access for Concrete and Abstract Words. *Journal of*

Experimental Psychology : Learning , Memory , and Cognition, *12*(1), 92–107.

Lachmair, M., Dudschig, C., De Filippis, M., de la Vega, I., & Kaup, B. (2011). Root versus roof: automatic activation of location information during word processing. *Psychonomic Bulletin & Review*, *18*(6), 1180–1188. https://doi.org/10.3758/s13423-011-0158-x

Lewis, G., & Poeppel, D. (2014). The role of visual representations during the lexical access of spoken words. *Brain and Language*, *134*, 1–10. https://doi.org/10.1016/j.bandl.2014.03.008

Lynott, D., & Connell, L. (2013). Modality exclusivity norms for 400 nouns: the relationship between perceptual experience and surface word form. *Behavior Research Methods*, *45*(2), 516–526. https://doi.org/10.3758/s13428-012-0267-0

Marslen-wilson, W. D. (1987). Functional parallelism in spoken word-recognition. *Cognition*, *25*, 71–102.

Martin, C. B., Douglas, D., Newsome, R. N., Man, L. L. Y. Y., & Barense, M. D. (2018). Integrative and distinctive coding of visual and conceptual object features in the ventral visual stream. *ELife*, *7*, 1–29. https://doi.org/10.7554/eLife.31873

Mattioni, S., Rezk, M., Battal, C., Bottini, R., Mendoza, K. E. C., Oosterhof, N. N., & Collignon, O. (2020). Categorical representation from sound and sight in the ventral occipito-temporal cortex of sighted and blind. *ELife, 9*, 1–33. https://doi.org/10.7554/eLife.50732

Morey, R. D., Rouder, J. N., & Jamil, T. (2018). BayesFactor: Computation of Bayes Factors for common designs. R package version 0.9. 12-4.2.

Morucci, P., Bottini, R., & Crepaldi, D. (2019). Augmented Modality Exclusivity Norms for Concrete and Abstract Italian Property Words. *Journal of Cognition*, *2*(1), 1–14.

Ostarek, M., & Bottini, R. (2021). Towards strong inference in research on embodiment - Possibilities and limitations of causal paradigms. *Journal of Cognition*.

Ostarek, M., & Huettig, F. (2017). A Task-Dependent Causal Role for Low-Level Visual Processes in Spoken Word Comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 1–32. https://doi.org/http://dx.doi.org/10.1037/xlm0000375

Ostarek, M., Joosen, D., Ishag, A., de Nijs, M., & Huettig, F. (2019). Are visual processes causally involved in “perceptual simulation” effects in the sentence-picture verification task? *Cognition*, *182*(September 2017), 84–94. https://doi.org/10.1016/j.cognition.2018.08.017

Paivio, A. (1986). *Mental representations: A dual coding approach*. Oxford, UK: Oxford University Press.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: transforming numbers into movies. *Spatial Vision*. https://doi.org/10.1163/156856897X00366

R Core Team. (2013). R: A language and environment for statistical computing.

Reilly, J., Hung, J., & Westbury, C. (2017). Non-Arbitrariness in Mapping Word Form to Meaning: Cross-Linguistic Formal Markers of Word Concreteness. *Cognitive Science*, *41*(4), 1071–1089. https://doi.org/10.1111/cogs.12361

Reilly, J., & Kean, J. (2007). Formal Distinctiveness of High- and Low-Imageability Nouns: Analyses and Theoretical Implications. *Cognitive Science*, *31*(1), 157–168. https://doi.org/10.1080/03640210709336988

Reilly, M., & Desai, R. H. (2017). Effects of semantic neighborhood density in abstract and concrete words. *Cognition*, *169*, 46–53. https://doi.org/10.1016/j.cognition.2017.08.004

Schwanenflugel, P. J., Harnishfeger, K. K., & Stowe, R. W. (1988). Context availability and lexical decisions for abstract and concrete words. *Journal of Memory and Language*, *27*(5), 499–520. https://doi.org/10.1016/0749-596X(88)90022-8

Schwanenflugel, P. J., & Stowe, R. W. (1989). Context Availability and the Processing of Abstract and Concrete Words in Sentences. *Reading Research Quarterly*, *24*(1), 114–126.

Striem-Amit, E., Wang, X., Bi, Y., & Caramazza, A. (2018). Neural representation of visual concepts in people born blind. *Nature Communications*, *9*(1), 5250. https://doi.org/10.1038/s41467-018-07574-3

Vignali, L., Xu, Y., Turini, J., Collignon, O., Crepaldi, D., & Bottini, R. (2020). Timecourse and convergence of abstract and concrete knowledge in the anterior temporal lobe . *Bioarxiv*, 1–26.

Wang, X., Men, W., Gao, J., Caramazza, A., & Bi, Y. (2020). Two Forms of Knowledge Representations in the Human Brain. *Neuron*, *107*, 1–11. https://doi.org/10.1016/j.neuron.2020.04.010

Zwaan, R. A. (2016). Situation models, mental simulations, and abstract concepts in discourse comprehension. *Psychonomic Bulletin & Review*, *23*(4), 1028–1034. https://doi.org/10.3758/s13423-015-0864-x

Appendix 1. Italian words used in the experiment with English translation.

Abstract		Multimodal		Visual	
Italian	**English**	**Italian**	**English**	**Italian**	**English**
ammorbante	annoying	acerbo	unripe	abbagliante	dazzling
amorale	amoral	acido	acid	accecante	flashy
apatico	apathetic	alcolico	alcohol	amaranto	amaranth
astratto	abstract	appetitoso	appetizing	annerito	blackened
astringente	astringent	appiccicoso	sticky	arancione	orange
atipico	atypical	aromatico	aromatic	azzurro	light blue
clamoroso	clamorous	aspro	sour	bianco	white
concettuale	conceptual	bollente	boiling	brillante	brilliant
confuso	confused	caldo	hot	castano	chestnut brown
corretto	correct	caramellato	caramelized	colorato	colored
curativo	curative	cremoso	creamy	cromatico	chromatic
curioso	curious	deforme	deformed	fluorescente	fluorescent
dolente	sore	delizioso	delicious	fosforescente	phosphorescent
elusivo	elusive	dolce	sweet	fucsia	fuchsia
equo	fair	duro	hard	giallo	yellow
esitante	hesitant	fetido	fetid	grigio	grey
euristico	heuristic	fiammeggiante	flaming	incolore	colorless
fantasioso	imaginative	flaccido	flaccid	indaco	indigo
geniale	ingenious	fragrante	fragrant	ingrigito	graying
illusorio	illusory	fresco	fresh	luccicante	glittering
inconscio	unconscious	fruttato	fruity	marrone	brown
inerente	inherent	gelido	chill	monocolore	single color
lieve	slight	gustoso	tasty	monocromatico	monochrome
logico	logical	mielato	honey	nero	black
meditato	considered	pepato	peppery	nitido	clear
mentale	mental	piagnucolante	whining	olivastro	olive
mistico	mystical	piccante	spicy	purpureo	purple
ponderato	thoughtful	puzzolente	smelly	rilucente	bright
puro	pure	rancido	rancid	risplendente	shining
ragionato	reasoned	rovente	scorching	rosa	rose
razionale	rational	ruvido	rough	rosso	red
relativo	relative	sanguinante	bleeding	sbiadito	faded
saggio	wise	saporito	tasty	scarlatto	scarlet
sensato	sensible	sferico	spherical	sfavillante	sparkling
stucchevole	sickly	simmetrico	symmetrical	sfumato	pale
teoretico	theoretical	soave	sweet	smagliante	dazzling
trascendente	transcendent	speziato	spicy	turchese	turquoise
tremendo	terrible	urticante	urticant	variopinto	multicolored
vago	vague	vellutato	velvety	verde	green
vero	true	zuccherato	sweetened	viola	purple