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

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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* benefit from 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). 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).

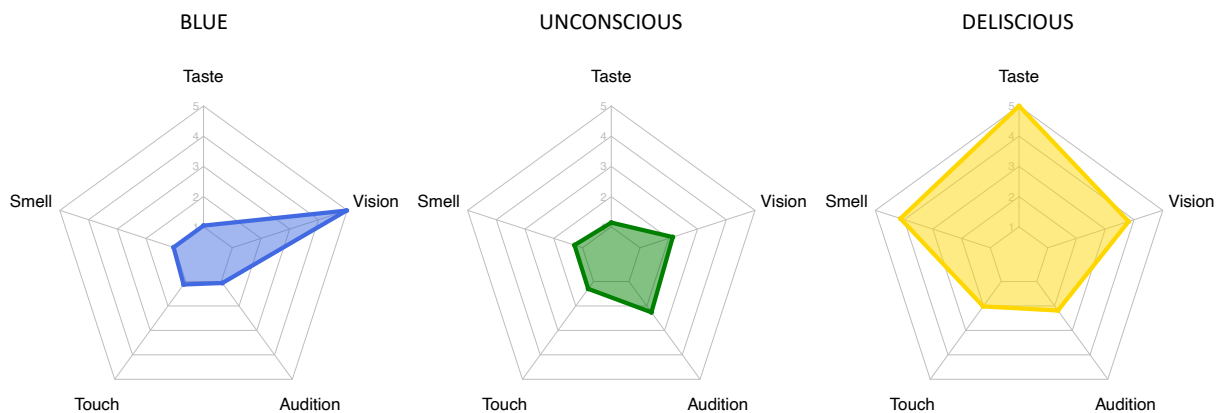


Figure 1. Spider plots representing the typical perceptual profile of a unimodal visual word (“blue”, left panel), an abstract word (“unconscious”, central panel), and a multimodal word (“delicious”, right panel).

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 analysis¹.

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.

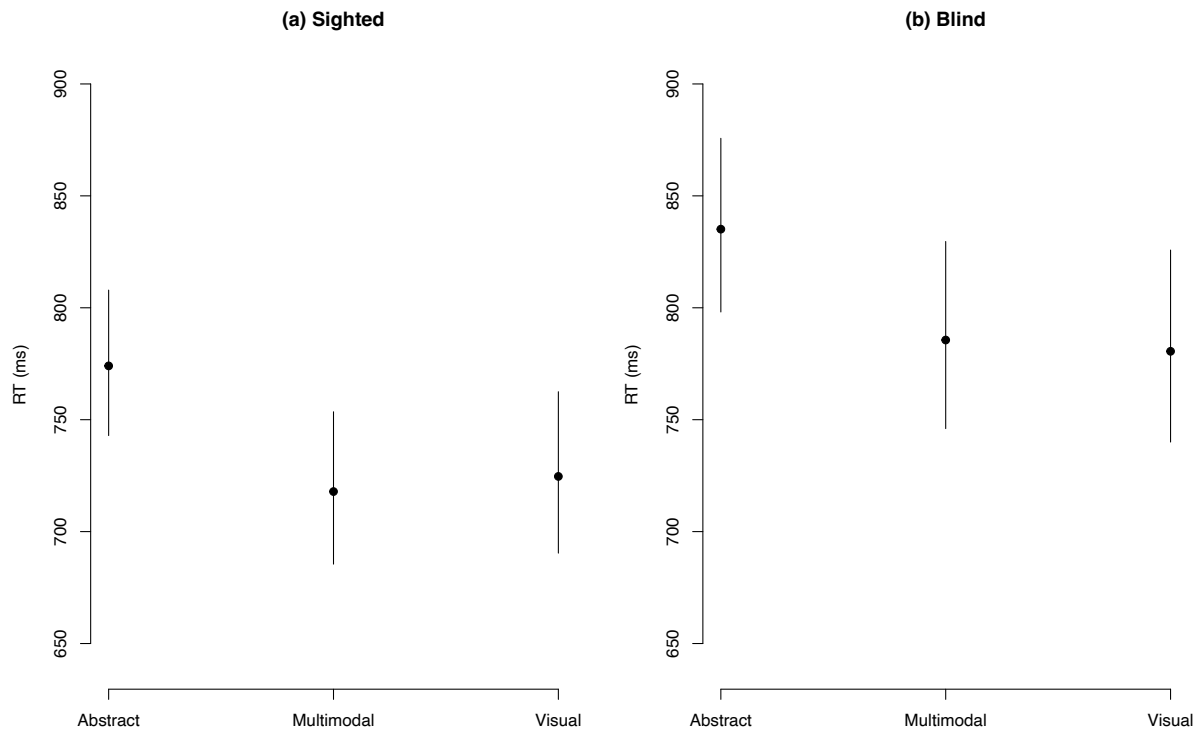


Figure 2 Results of Experiment 1. RTs model estimates for sighted and blind people across the three different semantic types. Error bars represent 95% confidence intervals.

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

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

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. RTs were inverse transformed to approach normality (although the same results are obtained analyzing raw RTs). 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 ($\text{Chisq}(1)= 5.70, p= 0.02$), and Semantic Type ($\text{Chisq}(2)= 127.51, p< 0.001$). The Semantic Type by Group interaction, instead, did not reach the significance threshold ($\text{Chisq}(2)= 3.66, p= 0.16$), and showed a very small Bayes Factor ($\text{BF} = 0.012$), indicating a negligible effect of the interaction term: the effect of Semantic Type is not statistically different in sighted and blind participants.

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: $\text{Chisq}(1)= 102.76, p< 0.001$) and multimodal words (Semantic Type: $\text{Chisq}(1)= 129.72, p< 0.001$), in line with a concreteness advantage. On the other hand, there was no significant difference between visual and multimodal words (Semantic Type: $\text{Chisq}(1)= 0.14, p= 0.71$).

Discussion

In this study we tested whether the concreteness effect in lexical decision tasks is driven

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

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 is not necessary to drive the concreteness effect. Is it possible that the concreteness 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).

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

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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