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BRIEF REPORT

The Concreteness Advantage in Lexical Decision Does Not Depend on Perceptual Simulations

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Abstract words are typically more difficult to identify than concrete words in lexical-decision, word-naming, and recall tasks. This behavioral advantage, known as the *concreteness effect*, is often considered as evidence for embodied semantics, which emphasizes the role of sensorimotor experience in the comprehension of word meaning. In this view, online sensorimotor simulations triggered by concrete words, but not by abstract words, facilitate access to word 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 because 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 with 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

Supplemental materials: https://doi.org/10.1037/xge0001090.supp

Concrete words are typically processed more quickly and accurately than abstract words in lexical-decision, word-naming, and recall tasks (Allen & Hulme, 2006; de Groot, 1989; Fliessbach et al., 2006; Kroll & Merves, 1986; Schwanenflugel & Stowe, 1989; Schwanenflugel et al., 1988). Why do words that refer to tangible entities, such as "cat" or "iron," beneficiate this processing advantage compared with 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 are easier to contextualize (Schwanenflugel et al., 1988), thus leading to faster recall and recognition. Alternatively, ease of processing may be a direct consequence of the perceptual bases of concrete concepts: Words that refer to

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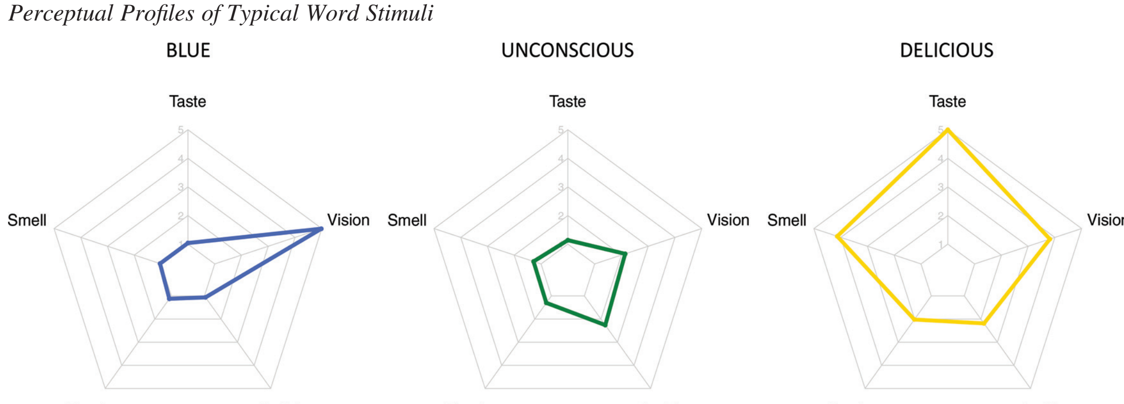
tangible things may activate perceptual knowledge that is not readily available for abstract concepts (Connell & Lynott, 2012; Paivio, 1986). According to this approach, retrieving conceptual knowledge (e.g., the concept of "red") consists, at least in part, of reactivating sensorimotor processes related 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 et al., 2014; Lachmair et al., 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 ES, verbal representations play a rather marginal role (but see Andrews et al., 2009), and abstract concepts can be represented via (more complex) simulations, such as situational models (Zwaan, 2016), relational schemas (Barsalou et al., 2018), or multimodal abstractions (Barsalou, 2016; Binder, 2016), to name a few. Thus, if processing abstract concepts requires the recruitment of more complex simulatory mechanisms compared with concrete ones (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 (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 high strength in touch but also sight, maybe some strength in taste, and very little strength in smell and audition (see Figure 1). From these norms, it is easy to extract the 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 online 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 the association of 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 color words is represented in the anterior temporal lobe (ATL) in both the sighted and the blind, whereas a similar activation in color-related visual regions (V4 complex) was found only for the sighted (Bottini et al., 2020; Wang et al., 2020). This result confirms the lack of visual sensory simulations in the blind, although the meaning of visual words 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 (nonvisual) sensory experience (e.g., red might remind one of a rose) and thus differentiate 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 one of a rose). Moreover, a functional magnetic resonance imaging (fMRI) study that compared directly abstract and visual words in congenitally blind people found that these two types of semantic knowledge

Figure 1

Perceptual Profiles of Typical Word Stimuli



Note. 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). See the online article for the color version of this figure.

showed a similar neural profile (activating overlapping regions in the ATL) with no additional sensorimotor activation related to visual words (Striem-Amit et al., 2018).

In our experiment, participants engaged in a lexical-decision task that included abstract words (denoting nontangible properties; e.g., "true"), concrete multimodal words (denoting properties that can be perceived with several senses and can also be perceived 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 with abstract words) should disappear or be significantly reduced in blind people.

Method

Participants

In total, 42 volunteers (21 early blind [EB]; 21 sighted controls [SC]) were recruited for the experiment in exchange for payment. They were all native Italian 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 the online supplemental 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 participants (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 3 and reported no visual memories. All participants were blindfolded during the experiment. The ethics committee of the University of Trento approved this study (Protocol 2017-020), and participants gave their informed consent before participation.

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 et al., 2019; see Appendix). Following Connell and Lynott (2012), we used MPS to distinguish between abstract and concrete items. The list of abstract words includes items with low values of MPS (mean [*M*] = 2.88, standard deviation [*SD*] = .63), whereas concrete multimodal (*M* = 4.77, *SD* = .28) and concrete visual (*M* = 4.91, *SD* = .11) words were very high in MPS. In order to distinguish between concrete visual and multimodal words, we relied on the modality exclusivity score proposed by Connell and Lynott (2012). Concrete visual unimodal words had overall very high values in modality exclusivity (*M* = .83, *SD* = .1, on a 0–1 scale) compared with concrete multimodal words (*M* = .39, *SD* = .08), and their dominant modality was always vision (see Table 2). Overall values for frequency, number of syllables, length in phonemes, and familiarity were 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 online supplemental materials) showed that familiarity ratings between the

Table 1
Early Blind (EB) and Sighted Control (SC) Participant Information

Early blind	Age	Gender	Years of formal education	Age onset blindness	Etiology	Sighted control	Age	Gender	Years of formal education
EB_01	54	F	13	0	Congenital retinitis pigmentosa	SC_01	51	F	13
EB_02	46	F	13	0	Bilateral congenital microphthalmia	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/ Retrolental fibroplasia	SC_06	43	F	13
EB_07	27	M	11	0	Peters's 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 microphthalmia	SC_19	32	F	16
EB_20	29	F	13	2	Retinoblastoma	SC_20	26	F	13
EB_21	30	M	13	0	Retinitis 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

Table 2
Psycholinguistic Variables Matched Across Semantic Type

Psycholinguistic variable	Abstract	Multimodal	Visual
Number of syllables	3.43 (0.81)	3.38 (0.87)	3.38 (0.98)
Number of 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)

Note. Values in parentheses indicate the standard deviation.

sighted and the blind were highly correlated ($r > .88$) and that adding this figure to the regression model left the results unchanged.

It is well known that spoken words may in some cases be 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" and "na") is compatible with a single lexical entry (i.e., "banana"). Thus, we aligned our analysis of response time (RT) 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; http://crr.ugent.be/subtlex-it/). 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 by 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-word 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.

Procedure

Stimuli were presented to participants via headphones using Matlab Psychtoolbox (Brainard, 1997; Pelli, 1997). The intertrial interval varied randomly from 1,500 to 2,500 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 participant's dominant hand. After each word, participants had 3 sec 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 six 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., 2020).

Results

We first analyzed 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 that of 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 the sighted and the 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 groups. Both in sighted and in blind participants, accuracy was slightly lower for abstract words (SC = 98%, EB = 97%) compared with concrete visual (SC = 99%, EB = 99%) and multimodal (SC= 99%, EB = 98%) words. However, not surprisingly, participants were clearly at the ceiling here; thus, we focused on the analysis of the reaction times.

We removed from the analysis all the inaccurate trials (1.75%), plus a few data points with RTs lower than 300 ms (.02%). RTs were calculated from the UP of each word (see Method section).[2] A linear transformation was applied by adding the mean of the UPs to all trials in order to avoid negative values in the few cases (10% of the data points) 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 data points), inverse transformed to approach normality, and analyzed using a linear mixed-effect regression through the package lme4 (Bates et al., 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 et al., 2018) for the interaction effect to account for the potential lack of a difference between groups.

Results (see Figure 2) showed a main effect of group, $\chi^2(1) = 5.70$, $p = .02$, and semantic type, $\chi^2(2) = 127.51$, $p < .001$). The Semantic Type × Group interaction, however, did not reach the

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

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

[3] The results did not change when raw RTs were considered (including negative ones) and neither trimming nor transformation was applied: main effect of group, $\chi^2(1) = 4.81$, $p = .03$; semantic type, $\chi^2(2) = 145.93$, $p < .001$; Semantic Type × Group interaction, $\chi^2(2) = 4.37$, $p = .11$.

significance threshold, $\chi^2(2) = 3.66$, $p = .16$, and showed a very small Bayes factor (.012), indicating a negligible effect of the interaction term; the effect of semantic type was not statistically different in sighted and blind participants.

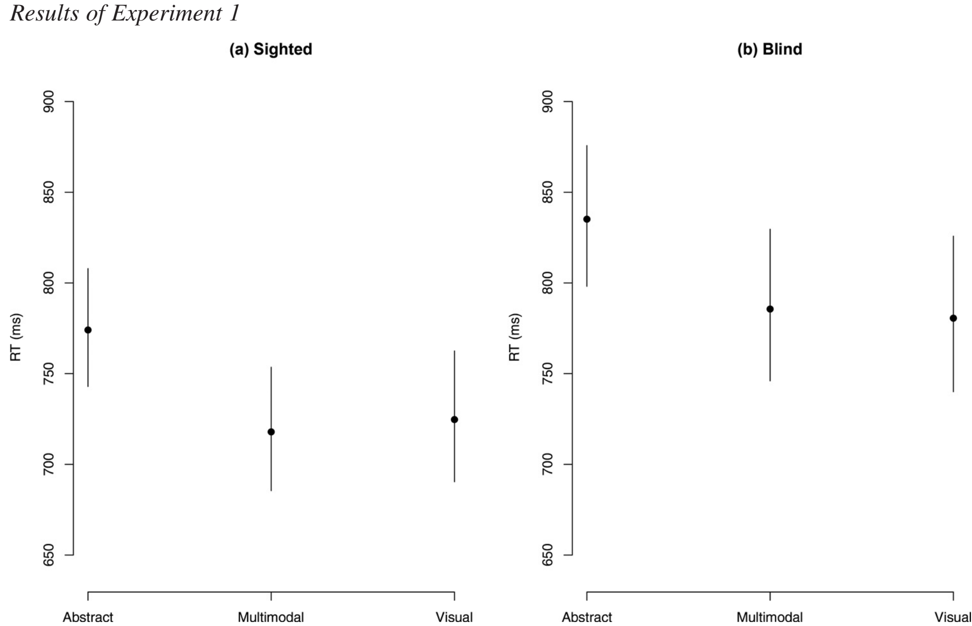
To clarify the pattern of results, we unpacked the overall main effect of semantic type via post hoc pairwise comparisons. Critically for our predictions, abstract words elicited slower RTs than visual, semantic type: $\chi^2(1) = 102.76$, $p < .001$, and multimodal words, semantic type: $\chi^2(1) = 129.72$, $p < .001$, in line with a concreteness advantage. On the other hand, there was no significant difference between visual and multimodal words, semantic type: $\chi^2(1) = .14$, $p = .71$.

Discussion

In this study, we tested whether the concreteness effect in lexical-decision tasks is driven by online sensorimotor simulations. We found that blind people processed concrete words faster than abstract words, exactly like their sighted counterparts. 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 online 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, just as for sighted people, abstract concepts such as "quark" or "unconscious" are intelligible; Striem-Amit et al., 2018). Instead, we found that visual words benefited the same processing advantage in both the sighted and the blind, suggesting that sensorimotor simulations are not necessary to drive the concreteness effect. Is it possible that the concreteness is effect is driven by online simulations in the sighted but not in the blind? We consider this unlikely. For instance, a previous study using a causal manipulation has shown that visual noise does not interfere with the concreteness effect during lexical decisions in sighted people (Ostarek & Huettig, 2017), as a simulationist account would predict. This result, together with our current study, suggests that the concreteness advantage during lexical decisions 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 et al., 2020) showed that animacy judgment of 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 et al., 2018). Accordingly, there is evidence that differences between the sighted and the blind in processing color concepts emerge when explicit color-related processing is required, both at the behavioral (Connolly et al., 2007; Kim et al., 2019) and the neural level (Bottini et al., 2020; Wang et al., 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 the sighted and the 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

Figure 2
Results of Experiment 1



Note. Reaction times (RTs) model estimates for sighted and blind people across the three different semantic types. Error bars represent 95% confidence intervals (Fox & Weisberg, 2018).

on processing demands (Bottini et al., 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 online sensorimotor simulations, yet sensorimotor simulations seem to play a functional role in conceptual processing in other contexts, especially (but not exclusively) when task demands require an explicit recall of perceptual knowledge (Ostarek & Huettig, 2017; Ostarek et al., 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 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), and formal aspects such as the phonological and morphological structure of words (Reilly & Kean, 2007; Reilly et al., 2017). 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.

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Appendix

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

(*Appendix continues*)

Appendix (*Continued*)

Abstract		Multimodal		Visual	
Italian	English	Italian	English	Italian	English
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

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