Visual content of words delays negation

Isabel Orenes *, Carlos Santamaría

Universidad de la Laguna, Tenerife, Spain

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ABSTRACT

Many studies have shown the advantage of processing visualizable words over non-visualizables due to the associated image code. The present paper reports the case of negation in which imagery could slow down processing. Negation reverses the truth value of a proposition from false to true or vice versa. Consequently, negation works only on propositions (reversing their truth value) and cannot apply directly to other forms of knowledge representation such as images (although they can be veridical or not). This leads to a paradoxical hypothesis: despite the advantage of visualizable words for general processing, the negation of clauses containing words related to the representation of an image would be more difficult than negation containing non-visualizable words. Two experiments support this hypothesis by showing that sentences with a previously negated visualizable word took longer to be read than sentences with previously negated non-visualizable words. The results suggest that a verbal code is used to process negation.

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1. Introduction

Negation is essential in language comprehension since it is present in all natural and artificial languages and is used by children from an early age. Its functional in sentential logic is to take a proposition and reverse its truth value (reverting false to true and vice versa). In other words, if the proposition *P* is false (e.g., Pope Francis is a Marxist), then *Not P* is true (e.g., Pope Francis is not a Marxist) and vice versa (Aristotle, 1984). *Propositions* are the smallest units of knowledge that can be true or false. Consequently, the traditional view is that negation works only on propositions (reversing their truth value) and cannot apply directly to other forms of knowledge representations such as images that are not in principle true or false arguments. From this point of view, negation cannot have a perceptual representation.

However, some authors have defended recently an alternative account where negation does apply directly to images (Oversteegen & Schilperoord, 2014; see also Waskan, 2006). They presented images and observed that participants described them with a negation. Negation could be one interpretation among others. For example, the image of a face without a mouth could be interpreted as 'the woman does not have a mouth', or 'silent', or 'be quiet in the room' or 'rights for women'. Nevertheless, all these interpretations do not tell us what negation means, but what the image means, and images have many interpretations. Following Wittgenstein (1953), Johnson-Laird (2006) pointed

out that we could superimpose an image of a large red cross on the image of a cabinet behind the piano to represent: 'the cabinet is not behind the piano', or we also could represent the cabinet in front of the piano, to the left of the piano, to the right of the piano, below the piano, and so on. Nevertheless, we would have to know that a cabinet in front of the piano or a large cross on the image of a cabinet behind the piano means, 'the cabinet is not behind the piano' because nothing in the image captures the meaning of negation: if a proposition is true then its negation is false, and vice versa. Of course, an image can be veridical or not with respect to reality or to a sentence, but there is no way to draw an image signifying that 'the cabinet is not behind the piano'. We can draw images that are compatible with this sentence, but the negation included cannot be captured without symbolic operation.

Concepts differ in imageability, and the ease with which we can represent a concept with an image will affect how we process it. Concrete concepts are processed more quickly and accurately than abstract concepts in a variety of tasks, such as word recognition, lexical decision, recall, problem-solving, and reasoning (for a review of the classical concreteness effect, see Denis, 1989). Indeed, this effect has been related to an image code that could be implicated in the processing of concrete concepts but not of abstract concepts. This dual coding theory (Paivio, 1991, 2013) has found support in recent neuroimaging studies showing that neural representations of concrete concepts, while involving both an image code and a verbal code, tend to rely more heavily on the former, while the representation of abstract concepts relies more heavily on the latter (see Wang, Conder, Blitzer, & Shinkareva, 2010 for a meta-analysis). The advantage of concrete concepts over abstract concepts could be related to the greater processing demands needed

* Corresponding author at: Universidad de La Laguna, Departamento de Psicología Cognitiva, Campus Guajara, sn, 38205 La Laguna, Tenerife, Spain. Tel.: +34 922 317503.
E-mail addresses: iorenes@ull.es (I. Orenes), csantam@ull.es (C. Santamaría).

to construct images (cf. Johnson-Laird & Bethell-Fox, 1978). This type of representation is more structured and elaborated than verbal representation, and consequently leads to a richer and deeper semantic processing (cf. Craik & Tulving, 1975).

We decided to use visualizable and non-visualizable words instead of concrete or abstract concepts. The main reason underlying this choice was that it is unclear exactly what information is captured by concreteness. For example, imageability and concreteness, though technically different psycholinguistic constructs, are closely related: imageability ratings explain more than 72% of the variance in concreteness ratings (Reilly & Kean, 2007). In Paivio (2013), concreteness is defined in terms of the directness of the sensory reference that can be determined using a dictionary, while imageability is defined as a psychological attribute that can be inferred only from psychological measures. Also, concreteness can refer to five different modalities: visual, auditory, haptic, gustatory and olfactory. Connell and Lynott (2012) demonstrated the relationship between concreteness, imageability and each of these modalities. They also studied how these variables affect lexical decision and naming tasks. The conclusion was that perceptual strength ratings are the better predictor, and so concreteness effects could be best characterized as perceptibility effects. In sum, it would be advisable, for our purposes, to base our study on visualizable words instead of on concreteness because the former is a specific variable, and we therefore have more control over it.

Taken together, this means that visualizable words will be easier to process, as they are represented using image codes; however, negation applies only to propositions (or verbal codes), not to images. This yields a paradoxical situation: visualizable words should be easier to process than words that are not visualizable, whereas negation should reverse the effect. Negation applies only to the verbal code, and so the activation of the image code in the case of visualizable words is irrelevant and may even impede processing.

To test this hypothesis, we carried out two experiments using a subtle methodology. In Experiment 1, there were two conditions depending on whether the negation was applied to a visualizable or non-visualizable word. Each trial had two sentences. Each sentence contained two adjectives, one referring to a property that would be easy to visualize (the visualizable word; e.g., asleep) and the other referring to a property that was hard to visualize (the non-visualizable word; e.g., brave). In the first sentence, one of these two words was negated (i.e., for the visualizable condition: *The boy was brave and he was not asleep*). This negated word was replaced with an antonym in the second sentence (i.e., *The boy was brave and he was awake*). This methodology allows us to have the same target (the second sentence) for visualizable and non-visualizable conditions. An example for the non-visualizable condition would be as follows: *The boy was awake and he was not cowardly. The boy was awake and he was brave*. Readers should note that the second sentences of both conditions are similar, thus avoiding possible lexical and sub-lexical effects, among others (the same words were used throughout the experiment for each condition). To date, this control has not been introduced in other paradigms that employed different targets and allows us to control lexical and sub-lexical effects. For example, Tettamanti et al. (2008) used *Now I push the button* as an action condition and *Now I appreciate the loyalty* as an abstract condition.

The dependent variable of Experiment 1 was the time that participants took to read the second sentence. The predicted result is that participants should take longer to read the second affirmative sentence (the target sentence) after a sentence containing a clause with a negated visualizable word than after a sentence containing a clause with a negated non-visualizable word. It should be harder to understand the negation of a visualizable word than the negation of a non-visualizable word, and as a consequence, it should be harder to understand its equivalent affirmative in the second sentence. We measured the second sentence instead of the first because the second sentence is similar for both conditions, and we wanted to be sure that the effects are due to the kind of words negated (visualizable or not), and not to other properties of different words.

In Experiment 1, the first sentence had a negative clause (e.g., *The boy was not asleep*) and the second sentence expressed the same proposition in an affirmative clause (e.g., *The boy was awake*). Many studies have shown that in binary negation (see Wason, 1961), predicates such as "asleep" and "awake" in which the negation of one implies the affirmation of the other, participants tend to transform a negation, such as "not asleep" into "awake" (see also Kaup, Lüdtke, & Zwaan, 2006). Therefore, it is arguable that our results are a consequence of the representation of the affirmative alternative rather than the negation. To rule out this possibility, we designed Experiment 2, in which the negative concepts were preserved in the target sentences. Here, we used sets of three sentences, such as:

John said that the boy was brave and he was not awake.
John was wrong.
The boy was brave and he was awake.

With this change, the third sentence (the target) used the same words as the first one (brave and awake). On half the trials, the third assertion was inconsistent with John´s assertion (see example above) and in the other half it was consistent with his assertion, such as:

John said that the boy was brave and he was not asleep.
John was right.
The boy was brave and he was awake.

Both clauses in the third assertion were always affirmative. The predicted result was that participants should be faster to read the third sentence when the first sentence contains a negated non-visualizable word than when it contains a negated visualizable word, as in Experiment 1.

2. Experiment 1

The aim of Experiment 1 was to test whether the negation of clauses containing visualizable words would be slower than the negation of clauses containing non-visualizable words when we presented the alternative affirmation.

2.1. Method

2.1.1. Participants

Eighty-two native Spanish speakers from the University of La Laguna, Tenerife (Spain), participated in the experiment in exchange for course credits.

2.1.2. Materials and procedure

Two normative studies were carried out before the experimental study.

2.1.2.1. The first normative study. The goal of the first normative study was to select the material, which consisted of visualizable and non-visualizable words with clear antonyms. We presented 80 sentences (20 pairs of visualizable and non-visualizable words and their antonyms $(20 \times 4 = 80)$). Seventy-six students of the University of La Laguna (64 females; mean age: 22 years), different to those forming the experimental sample, had to write the antonym of each word and estimate the degree of visualization in the choice using a Likert scale from 1 to 5. For example, *The boy was asleep. The boy was…* The underlined words were obtained from the Spanish free-association norms (Fernández, Díez, Alonso, & Beato, 2004). All the experiments were carried out in Spanish (including all the materials and instructions and the crucial words), which, for the convenience of readers, we have translated here into English. The selection criterion for visualizable and non-visualizable words was that they must have a clear antonym, i.e., the percentage of agreement about the antonym must be above

Table 1
Mean values for characteristics of stimuli.

	Experiment 1		Experiment 2	
	Visualizable	Non-visualizable	Visualizable	Non-visualizable
Frequency	1.46	1.65	1.63	1.44
Number of syllables	3	3	3	3
Number of letters	7.10	6.60	6.22	6.67
Agreement on the antonym	98%	97%	98%	94%
Degree of visualization	4.12	2.63	4.29	2.73

90%. Following this criterion, half of the items were eliminated, leaving 40 words for use in the experimental study. Visualizable (20) and non-visualizable (20) words were equated for word frequency, number of syllables, and letters (see Table 1). We used BPAL to determine the words' characteristics (Davis & Perea, 2005). There was also no difference between visualizable and non-visualizable words with respect to the percentage of participants' agreement on the antonym. The only difference between them was the degree of visualization ($t(75) = 14.157$, $p < .001$; see Table 1).

2.1.2.2. The second normative study. The goal of the second normative study was to reproduce with our material the typical concreteness effect observed in lexical decision tasks, i.e., to obtain faster decision times for visualizable words than for non-visualizable words. Fifty-three native Spanish speakers from the University of La Laguna, Tenerife (Spain), participated in the study in exchange for course credits. These were not the same participants as those used in the experimental sample. We presented the 80 words (40 visualizable and 40 non-visualizable words) used in Experiments 1 and 2 and 80 pseudowords that were created from these words, which thus kept the same properties: letters, frequency of letters, etc. Each trial started with a fixation crosshair for 400 ms, followed by the string that remained on the screen for 2000 ms or until a response was given. Finally, a black screen appeared with the indication 'please, press the SPACE bar to continue'. The experiment started with six practice trials and all stimuli were presented in a random order. To indicate whether or not a string was a Spanish word, participants were asked to position their left and right index fingers on two response buttons marked yes/no. The experiment lasted approximately 5–10 min. The participants completed the experiment in an individual cubicle, and the instructions and trials were presented via the program E-PRIME 2.0 in a PC with CRT screen. An ANOVA comparing lexical decision latencies across words (663 ms; SD = 83) and pseudowords (788 ms; SD = 112) indicated a significant lexical effect ($F(1,52) = 179.359$, $p < .001$): words were identified faster than pseudowords. In addition, lexical decisions were faster for visualizable words (656 ms; SD = 87) than for non-visualizable words (670; SD = 83; ($F(1,52) = 6.468$, $p = .014$). This result showed the classical concreteness effect and the well-known advantage of visualizable words in lexical decision tasks.

2.1.2.3. The experimental study. Based on the results of the first normative study, we presented 40 experimental trials preceded by four practice trials. Each trial had two sentences. The first presented the description of either a person or an object through two words, one visualizable and one non-visualizable, one of which was negated. For example, *The boy was awake and he was not cowardly* (translated as 'el niño estaba despierto y no era cobarde'). Participants had to read the sentence and press the button as soon as possible after reading it. Then a second sentence with similar meaning appeared, but in this case the negated word was replaced by its antonym (e.g., *The boy was awake and he was brave*— translated as 'el niño estaba despierto y era valiente'). Half of the sentences negated the visualizable word (e.g., *The boy was brave and he was not asleep*—translated as 'el niño era valiente y no estaba dormido'/*The boy was brave and he was awake*—translated as 'el niño era valiente y estaba despierto') and half negated the non-visualizable

word (see the first example above). The second, target sentence was similar for both visualizable and non-visualizable conditions (only the order was altered; see Table 2). The predicted result was that the response to the target sentence after the negation of visualizable words should be slower than with non-visualizable words. The only task given to the subjects was to read each of the pairs of sentences and press the button as soon as they had finished reading each pair. Also, they were told that, in some cases, they would later receive a test for comprehension. Eighteen comprehension questions (e.g., *Was the boy brave?*) appeared at end of the trial to check that people were actually reading the sentences. In addition, 32 filler sentences were presented to reduce the participants' ability to predict the second sentence (e.g., *The apple was sweet and it was not red. The apple was organic*). The participants completed the experiment in an individual cubicle and the instructions and trials were presented to them via the program Presentation 12.1 in a PC with CRT screen.

2.2. Results and discussion

We removed two subjects whose reaction times were more than 2.5 standard deviations from the mean; thus, we analyzed 80 participants. Eighty-eight percent of the comprehension questions were responded to correctly, thus indicating that participants were reading and comprehending the sentences. We found that the visualizable target sentences (1734 ms; SD = 365) took longer to read than the non-visualizable target sentences (1693 ms; SD = 341), and these differences were significant ($t(79) = 2.295$, $p = .024$; d = .12). Hence, when a negative clause in an initial sentence contains a visualizable word, it is harder to understand in comparison with a non-visualizable word. This difference, in turn, impedes the reading time of the respective affirmative second sentences.

3. Experiment 2

The aim of Experiment 2 was to test whether the negation of clauses involving visualizable words would be slower than the negation of clauses with non-visualizable words when we presented the same negated concept instead of the alternative affirmation (Experiment 1). We presented the same word in sentences 1 and 3 (the target) in order to obviate any possible confounds that might have occurred in Experiment 1 as a result of differences in the time to read antonyms of visualizable and non-visualizable words.

3.1. Method

3.1.1. Participants

Ninety-two native Spanish speakers from the University of La Laguna, Tenerife (Spain), participated in the experiment in exchange for course credits.

3.1.2. Material and Procedure

We took 80 words from the first normative study, including 40 visualizable and 40 non-visualizable words. We added more words in this experiment for two reasons: 1) to strengthen our data and 2) because the percentage of agreements about the antonyms was not

Table 2
Examples of experimental sentences of Experiments 1 and 2.

	Visualizable condition	Non-visualizable condition
Experiment 1	The boy was brave and he was not asleep.	The boy was awake and he was not cowardly.
	The boy was brave and he was awake.	*The boy was awake and he was brave.*
Experiment 2	John said that the boy was brave and he was not asleep.	John said that the boy was awake and he was not cowardly.
Change to the alternative	John was right.	John was right.
	The boy was brave and he was awake.	*The boy was awake and he was brave.*
Retain the negated concept	John said that the boy was brave and he was not awake.	John said that the boy was awake and he was not brave.
	John was wrong.	John was wrong.
	The boy was brave and he was awake.	*The boy was awake and he was brave.*

important in this experiment. In Experiment 2, this percentage was higher for visualizable words than for non-visualizable words (98%/94%; $t(78) = 3.055, p = .003$) and there were differences in the degree of visualization (4.29/2.73; $t(78) = 17.529, p < .001$). The words were equated for frequency, number of syllables, and letters (see Table 1).

The participants carried out 80 trials. Each trial started with the description of a person, in which either a visualizable word (e.g., *John said that the boy was brave and he was not asleep*) or a non-visualizable word (e.g., *John said that the boy was awake and he was not cowardly*) was negated. The next sentence established whether the description was right (e.g., *John was right*) or wrong (e.g., *John was wrong*). The trial finished with the target sentence, which was similar for all conditions but with the order of words altered. In sum, we created four conditions (see Table 2). In the first two conditions, people had to retain the negated concept: 1) when negation involves a visualizable word and the information is inconsistent (e.g., *John said that the boy was brave and he was not awake. John was wrong. The boy was brave and he was awake*); and 2) when negation involves a non-visualizable word and the information is inconsistent (e.g., *John said that the boy was awake and he was not brave. John was wrong. The boy was awake and he was brave*). The next conditions are similar to Experiment 1, in that people had to change to the alternative: 3) when negation involves a visualizable word and the information is consistent (e.g., *John said that the boy was brave and he was not asleep. John was right. The boy was brave and he was awake*); and 4) when negation involves a non-visualizable word and the information is consistent (e.g., *John said that the boy was awake and he was not cowardly. John was right. The boy was awake and he was brave*). Each sentence appeared successively according to the reader's own pace. Also, 34 filler sentences similar to Experiment 1 were presented. The only task given to subjects was to read the sentences and to press the button as soon as possible. Some comprehension questions checked that people were actually reading the sentences. The participants carried out the experiment in an individual cubicle and the instructions and trials were presented to them via the program Presentation 12.1 in a PC with CRT screen.

3.2. Results and discussion

We removed ten subjects whose reaction times were more than 2.5 standard deviations from the mean, thus we analyzed 82 participants. 91% of the comprehension questions were responded to correctly, thus indicating that participants were reading and comprehending the sentences. There was an interaction in the third assertion between conditions ($F(1,81) = 4.612, p = .035$; see Table 3). A designed comparison revealed that participants took longer to read the target when they had to retain the negated visualizable word (1933 ms; SD = 456) than when they had to retain the non-visualizable word

(1858 ms; SD = 437); $t(81) = 2.542, p = .013; d = .17$). There was no difference between the two targets when people had to change to the alternative visualizable word (1853 ms; SD = 418) and the non-visualizable word (1859 ms; SD = 436; $t(81) = -.209$, $p = .835$). These two conditions were similar to those presented in Experiment 1 in the sense that individuals needed to change to the alternative in the target sentence. One possible reason for the lack of difference would be that the difference between the visualizable and non-visualizable conditions found in Experiment 1 vanishes with the introduction of the second sentence (e.g., John was right) in Experiment 2. However, the second sentence, *John was wrong*, introduces another negation, possibly making comprehension more difficult, the result being that the studied effect is maintained as described above.

This effect of negation of visualizable and non-visualizable words indicate that the visualizable words contain details that are irrelevant to negation and could therefore slow down processing. In other words, according to dual coding theory (Paivio, 1991), visualizable words would be related to both image and verbal codes, while negation may use only verbal codes. Therefore, the image code that is also activated for a visualizable word could interfere with, or at least slow down, processing.

4. General discussion

Our experiments show that negation of visualizable words impedes later processing as compared to non-visualizable words. This finding sheds light on the current controversy between scholars arguing that all meanings of sentences can be represented in a perceptual modality (e.g., Aristotle, 1984; Barsalou, 2008; Glenberg, Robertson, Jansen, & Johnson-Glenberg, 1999) and those arguing that not all sentence meanings can be processed in this way (e.g., Khemlani, Orenes, & Johnson-Laird, 2012). Our results are not easy to explain for the advocates of the first option. Sentences that appeared after the negation of visualizable words took longer to be read than those appearing after non-visualizable words, even though visualizable words took less time to read than non-visualizable words in a lexical decision task with the same material. Both results constitute converging evidence of a different representation of visualizable and non-visualizable words.

These results fit well with theories that distinguish between an image code and a verbal code, such as the dual coding theory (Paivio, 1983) or the mental model theory (Johnson-Laird, 1983). Also, Barsalou (2008) pointed out that the simulation system is closely integrated with the linguistic system. From all these points of view, the role of imagery is crucial in language, memory, problem solving and reasoning in order to improve performance, although this advantage could be reversed in certain cases, such as negation.

Table 3
The mean latencies (in msec) to read the second sentence in Experiment 1 and the third sentence in Experiment 2.

	Experiment 1	Experiment 2: change to the alternative	Experiment 2: retain the negated concept
Visualizable words	1734	1853	1933
Non-visualizable words	1693	1859	1858

Finally, it is important to note that our results may be not restricted to negation. Knauff and Johnson-Laird (2002; for a review: Knauff, 2013) found that visual relations slowed down the process of reasoning (relational inference and conditional reasoning) in comparison with control relations, visuospatial and spatial relations. The authors concluded that visual images are not critical for deductive reasoning and may even interfere with the process, whereas spatial representations help individuals to reason deductively. The authors reported studies showing an advantage for visual representation; however, it seems that these results are mainly due to the spatial rather than the visual properties of the materials (cf. De Soto, London, & Handel, 1965). Also, several studies have failed to detect any effect of imageability on reasoning (cf. Sternberg, 1980). Those results that have been corroborated in neuroimaging studies showed that only visual relations elicited additional activity in the visual cortex, while all types of relations evoked activity in the parietal cortex related to reasoning (Knauff, Fangmeier, Ruff, & Johnson-Laird, 2003). This hypothesis has been tested with participants who were blind from birth, and they were not affected by the visual-impedance effect (Knauff & May, 2006).

Before concluding, we would like to relate our results to certain theoretical proposals. The context availability theory holds that concrete concepts are more difficult than abstract concepts because of the effects of context (Kieras, 1978; Schwanenflugel & Shoben, 1983). According to this theory, concrete concepts can activate more semantic information in isolation than abstract concepts can. This increased activation would provoke the typical concreteness effect, which would nonetheless vanish if both types of concepts were presented in equally supporting sentence contexts. In Experiment 1, we presented a supportive context (e.g., *The boy was brave and he was not asleep*) and the second sentence (the target) was highly predictable (e.g., *The boy was brave and he was awake*); however, we did not obtain similar results for visualizable and non-visualizable conditions, as the context availability theory would predict.

A similar case occurs with the theoretical framework that posits *qualitative* differences in the organization of concrete and abstract concepts in the mental lexicon. According to this approach, concrete concepts are primarily organized following a *semantic similarity* principle, whereas abstract concepts are mainly organized by their *association* with other concepts (e.g., Crutch, 2006; Crutch, Ridha, & Warrington, 2006; Crutch & Warrington, 2005; Duñabeitia, Avilés, Afonso, Scheepers, & Carreiras, 2009). Experiment 1 showed that negation was understood faster for non-visualizable words than for visualizable words. This could be in keeping with the framework described above, if one assumed that non-visualizable words activated their associates, as occurred in the second sentence of Experiment 1 (e.g., not cowardly–brave). However, we obtained the same result in Experiment 2 when the same word (e.g., not cowardly–cowardly) was not presented with its associate. Thus, the associate is not the factor that explains the differences between the two types of words.

Recently, Kousta, Vigliocco, Vinson, Andrews, and Del Campo (2011) have found an advantage for abstract words over concrete words in a lexical decision task when the two types of words match in imageability and differ only in terms of emotionality (see also Barber, Otten, Kousta, & Vigliocco, 2013). We obtained the opposite results in a lexical decision experiment where imageability was manipulated. Both sets of findings could indicate that imagery is a necessary and sufficient factor for the concreteness effect because when this factor is present, we obtain the effect described in several studies in the literature; however, when this variable is absent, the effect disappears.

5. Conclusion

On the basis of our findings, we can conclude that when image representation yields information relevant to a process, as it does with mental rotation (Shepard & Cooper, 1982), then it will improve processing and performance. However, if visual images contain details that are irrelevant to a process, they may impede processing, thus increasing processing time. This leads to a more general and remarkable conclusion: negation (and presumably certain types of reasoning as well) must apply to symbolic or abstract representations and not to the image related to figuration and concreteness, details that may not be relevant for their processing.

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