

Numbers and prior knowledge in sentence comprehension

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Título: Números y conocimiento previo en comprensión de frases.

Resumen: Evaluamos si la comprensión de frases que contenían información numérica se beneficiaría de la presentación de números en formato arábigo y del uso del conocimiento previo. Los participantes leyeron frases que incluían números (dígitos arábigos o palabras numéricas) mientras se evaluaba la precisión de la comprensión. Además, las frases estaban sesgadas o no-sesgadas por el conocimiento previo de las personas sobre cantidades. Los resultados mostraron mejor comprensión de frases que contenían dígitos arábigos frente a palabras numéricas. Además, las frases sesgadas se comprendieron más precisamente que las frases no-sesgadas. Estos resultados indican que la información sobre magnitud en el contexto de frase se comprende mejor cuando las cantidades se presentan en formato arábigo y cuando están asociadas al conocimiento del mundo de los participantes.

Palabras clave: Conocimiento previo; comprensión de frases; procesamiento numérico.

Abstract: We evaluated whether the comprehension of sentences that contained numerical information could benefit from presenting numbers in Arabic format and from using prior knowledge. Participants read sentences including numbers (Arabic digits or number words) while the comprehension accuracy was evaluated. In addition, the sentences were biased or unbiased by people's prior knowledge about quantities. The results showed better comprehension for sentences that contained Arabic digits as compared to number words. Moreover, biased sentences were understood more accurately than unbiased sentences. These results indicate that information about magnitude in sentence context is comprehended better when quantities are presented in Arabic format and when they are associated with participants' world knowledge.

Key words: Prior knowledge; sentence comprehension; number processing.

Introduction

There is abundant research in numerical cognition focused on the comprehension of numbers (e.g., Macizo & Herrera, 2008; Noël & Seron, 1992; Serrano & Pons, 2008). These studies have evaluated the way people understand numbers with tasks that require the access to magnitude information (e.g., number comparison task in which participants decided the larger of two numbers). One basic finding obtained in this field is that number comprehension depends on the format in which numbers are presented (Macizo & Herrera, 2008). There is evidence indicating that semantic representation of numbers is activated whenever digits or number words are encountered (e.g., Ischebeck, 2003). However, there is evidence also that the access to semantic information is more accurate for Arabic digits (e.g., 21) than for number words (e.g., twenty-one). For example, people commit fewer errors in the Arabic number comparison task than in the verbal number comparison task (e.g., 4.6% and 6.1% respectively; Macizo & Herrera, 2008). The Arabic format is more simple and is used more frequently than the word-numeral system (Hurford, 1987), which might determine the easy to process digits as compared to number words.

In the majority of studies, number comprehension has been addressed in the absence of linguistic context although in real life numbers are usually immersed in rich linguistic contexts, for example, during the course of reading. To our knowledge, the easy to process Arabic numbers as compared to verbal number words has not been evaluated in context. How numerical information should be presented to improve reading comprehension? The first goal of this paper ad-

ressed this question. We evaluated whether numerical information in sentence context was better understood when it was presented in Arabic format as compared to verbal format.

The second aim of this study was to investigate whether the understanding of sentences with numerical information could benefit from the use of people's world knowledge. In the field of psycholinguistic research there is evidence that people use their knowledge of common events or situations in the world as they read texts, sentences and single words (Hare, Jones, Thomson, Kelly, & McRae, 2009; McKoon & Ratcliff, 2005; Vu, Kellas, Petersen, & Metcalf, 2003). Moreover, a variety of results demonstrates that activation of prior knowledge improves reading comprehension (Kintsch & Franzke, 1995). Kintsch and Franzke showed the necessity of prior knowledge for constructing a comprehensive representation of the reading. Readers without that prior knowledge could not make correct elaborative inferences, resulting in poorer understanding.

Related to magnitude processing, people have prior knowledge that helps them to mentally compare how tall, large, expensive, etc. things are in real life. For example, people tend to think that something made of gold is more expensive than something made of copper; however it might not be the case. Although world knowledge has been widely studied, we are not aware of any study investigating whether prior knowledge modulates the understanding of sentences that contain numerical information.

Summarizing, the present study aimed to answer two empirical questions. Firstly, in which format should numbers be presented to facilitate readers' comprehension? Second, would people's world knowledge facilitate the understanding of sentences with numerical information? In the study, participants read sentences that contained numbers (Arabic digits or number words) and, afterward, they completed a comprehension task to evaluate the sentence understanding. If the easy to process Arabic digits observed in the number

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comparison task (e.g., Macizo & Herrera, 2008) extend to number processing in context, we might find a better understanding of sentences with digits. Otherwise, number format (Arabic digits and number words) might not determine performance. In addition, some sentences were constructed so people's prior knowledge biased them toward the same interpretation as that associated to the literal meaning from comparing the two numbers in the sentence. If participants' prior knowledge facilitates number processing in context, they might show enhanced understanding of biased sentences as compared to unbiased sentences.

Method

Participants

Sixty-four students at the University of Granada (53 women, 11 men) participated in the experiment for course credits. All were native speakers of Spanish. They reported no history of language or numerical disabilities. Their mean age was 22.23 years ($SD = 4.76$). Four participants were left-handed, 60 were right-handed and all had normal or corrected-to-normal visual acuity. The participants were assigned randomly to the Arabic digits condition ($n = 32$) and to the Number words condition ($n = 32$). The participants gave written consent to participate before the experiment.

Design and Materials

A 2 x 2 mixed design was used with Number format (Arabic digits vs. number words) as a between-subjects (within-items) variable and Prior knowledge (biased vs. unbiased sentences) as a within-subjects (within-items) variable.

Eighty real-life situations were selected to compose the experimental sentences. These sentences contained two numbers. The numerical variables were controlled across the experimental sentences: Half of the sentences contained three-digit numbers (e.g., one hundred twenty-one) and the rest contained two-digit numbers (e.g., twenty-one). The two numbers embedded in each sentence had the same number of digits (two or three digits). The numerical distance between the two numbers in each sentence ranged from 1 (e.g., twenty-one vs. twenty-two) to 8 (e.g., twenty-one vs. twenty-

nine). Half of the sentences included within-decade comparisons (e.g., twenty-one vs. twenty-four) while the rest of sentences included between-decade comparisons (e.g., twenty-one vs. eighteen). For forty sentences, the first number was larger than the second number (e.g., twenty-four vs. twenty-one) while the second number in the rest of the sentences was larger than the first one (e.g., twenty-one vs. twenty-four).

Two stimulus lists were created in order to counterbalance the sentences across the biased and unbiased condition. Each list consisted of 80 sentences. Forty sentences were assigned to the biased condition and forty sentences were assigned to the unbiased condition. The sentences assigned to the biased condition in one list were assigned to the unbiased condition in the other list and vice versa. In each list the biased and unbiased conditions were equated for (a) the number of sentences containing two-digit numbers and three-digit numbers, (b) the numerical distance between the two numbers in each sentence, (c) the number of sentences containing within-decade comparisons and between-decade comparisons and, (d) the number of sentences in which the first number was larger (all $ps > .05$).

The experimental sentences were randomized within lists; all sentences appeared only once on each list and each participant saw only one list. A short practice list preceded the experimental trials. This list was constructed from a different set of eight sentences.

Two versions of each sentence were composed one for the biased condition and one for the unbiased condition (see Table 1 for additional examples). The unbiased sentences (e.g., "The copper bracelet costs one hundred and fifty eight euros while the tin bracelet costs one hundred and sixty six euros") described situations in which the participants' world knowledge did not determine what was larger, shorter, bigger, expensive, etc. (e.g., there is no bias to think that something made of copper is more expensive than something made of tin and vice versa). The biased sentences were composed by changing the unbiased sentences (e.g., "The copper bracelet costs one hundred and fifty eight euros while the gold bracelet costs one hundred and sixty six euros") so now the participants' world knowledge oriented to a specific senten-

Table 1. Examples of Material Used in the Study.

	Unbiased Sentences	Biased Sentences
<i>Example 1</i>		
Sentence	"Alfonso consumed 18 grams of alcohol drinking brandy and 11 grams of alcohol drinking vodka."	"Alfonso consumed 18 grams of alcohol drinking brandy and 11 grams of alcohol drinking wine."
Comprehension question	He consumed more alcohol drinking:	He consumed more alcohol drinking:
Response choices	"brandy" (True) "vodka" (False)	"brandy" (True) "wine" (False)
<i>Example 2</i>		
Sentence	"Portuguese people eat every year forty eight pizzas on average while Greek people eat forty six pizzas."	"Italian people eat every year forty eight pizzas on average while Greek people eat forty six pizzas."
Comprehension question	People eat more pizza in:	People eat more pizza in:
Response choices	"Portugal" (True) "Greece" (False)	"Italy" (True) "Greece" (False)

Note. The material was presented in Spanish (the approximated English translation is reported here).

ce interpretation (e.g., people tend to think that something made of gold is more expensive than something made of copper). In the biased sentences, the participants' prior knowledge supported the literal meaning of the sentences (i.e., the outcome of comparing the two numbers embedded in the sentences).

In order to control that biased sentences were really influenced by the participants' world knowledge as compared to the unbiased sentences, we conducted a normative study. Before performing the current experiment, the eighty sentences were presented to twenty participants from the same pool that those participating in the experiment (these participants did not take part in the experiment). They were asked to read clauses indicating the frequency, probability, quantity, etc., of something (e.g., the price of something) and then they rated three words (e.g., gold, copper, tin) according to the given dimension. The ratings ranged from 1 to 10, graded from less to more in the dimension. The rated words were those used to compose the biased and unbiased sentences. The results indicated that for a specific dimension, words used in biased sentences were rated higher (9.04, $SD = 0.54$) than words used in unbiased sentences (4.19, $SD = 0.48$), $t_1(19) = 30.26, p < .001$; $t_2(79) = 14.67, p < .001$.

Procedure

The experiment was controlled by a Genuine-Intel compatible 2993 MHz PC using E-prime experimental software, 1.1 version (Schneider, Eschman, & Zuccolotto, 2002). Participants were tested individually. They were seated approximately 60 cm from the computer screen. Stimuli were presented in lower-case black letters (Courier New font, 48 point size) on a white background. At this viewing distance, one character subtended a vertical visual angle of 1.91 degrees and a horizontal visual angle of 1.67 degrees.

Each trial started with a sentence presented in the middle of the screen. Participants had to read the sentence. They were encouraged to read at a normal reading rate. Right after finishing the reading, the participants pressed the space bar and a comprehension question appeared in the middle of the screen followed by two response choices centred on the middle of the screen, one on the right side and the other on the left side. Participants decided which response (right/left) was correct by pressing the required key (m/z), respectively. Accuracy on the button-press responses was encouraged over speed. The response choices remained on the screen until the participant's response and, after an inter-stimulus interval of 1000 ms the experiment continued with the next trial.

In half of biased sentences and half of unbiased sentences the correct response was on the right side while in the rest of trials the correct response was on the left side. The location of the correct response for each sentence was counterbalanced across participants.

Results

The mean accuracy in the sentence comprehension task was 87.1%. Analyses of variance (ANOVAs) were carried out on the mean percentage of correct responses by participants (F_1) and items (F_2) with Number format (Arabic digits vs. number words) as a between-subjects (within-items) variable and Prior knowledge (biased vs. unbiased sentences) as a within-subjects (between-items) variable.

In order to deal with a possible problem of unequal variance across experimental conditions, mean proportions of correct responses for each participant in each experimental condition were computed and analyses were performed with the arcsine transformation of these values. The main effect of number format was significant by participants, $F_1(1, 62) = 17.41, p < .001$, and items, $F_2(1, 79) = 19.89, p < .001$. The main effect of prior knowledge was significant by participants, $F_1(1, 62) = 27.20, p < .001$, and items, $F_2(1, 79) = 4.08, p < .05$. Finally, the Number format \times Prior knowledge interaction was not significant by participants or items, F_1 and $F_2 < 1$ (see Figure 1).

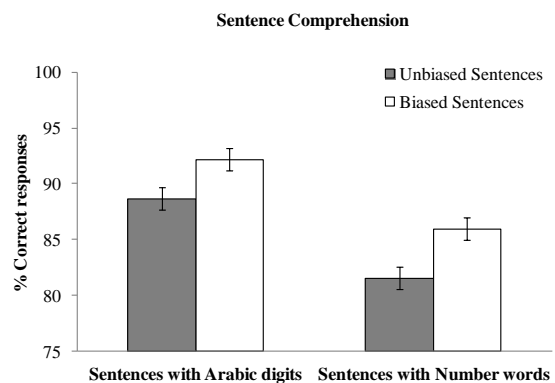


Figure 1. Percentage of correct responses obtained in the sentence comprehension task as a function of Prior knowledge (unbiased sentences vs. biased sentences) and Format of numbers in the sentences (Arabic digits vs. number words). Error bars refer to standard error.

It might be argued that the number of digits of numerical information embedded in the sentences might determine performance, so sentences with three-digit numbers might impose more cognitive load relative to sentences with two-digit numbers. To evaluate this hypothesis, an ANOVA was performed with Number format (Arabic digits vs. number words), Prior knowledge (biased vs. unbiased sentences) and Number of digits (two-digit numbers vs. three-digit numbers). The results showed a main effect of number of digits, $F_1(1, 62) = 25.96, p < .001$. Sentences with two-digit numbers were comprehended more accurately (89.25%, $SE = 0.84$) relative to sentences with three-digit numbers (84.79%, $SE = 0.93$). In addition, the only significant interaction including number of digits was the Number format \times Number of digits interaction, $F_1(1, 62) = 6.86, p < .01$. When sentences included Arabic digits, the effect of number of digits

was marginal, $F_1(1, 62) = 3.07, p = .08$. Comprehension accuracy for sentences with two-digit numbers was 91.22% ($SE = 1.18$) and for sentences with three-digit numbers it was 89.49% ($SE = 1.31$). When numbers were presented as number words, sentences with two-digit numbers were comprehended more accurately (87.28%, $SE = 1.18$) relative to sentences with three-digit numbers (80.07%, $SE = 1.31$), $F_1(1, 62) = 29.75, p < .001$. Thus, sentences with small numbers were associated to a better understanding which was more evident when numerical information was presented in verbal format.

Finally, we evaluated the possible numerical distance effect between the two numbers embedded in the sentence. To this end, an ANOVA was performed with Number format (Arabic digits vs. number words), Prior knowledge (biased vs. unbiased sentences) and Numerical distance (small: distance 1, and large: distance 8). The numerical distance was not significant, $p > .05$, and this variable did not interact with any other, $p_s > .05$. Thus, comprehension accuracy seems to be not sensitive to the numerical distance.

Discussion

Two empirical questions aimed the current study. Firstly, we examined whether sentence comprehension was more accurate when numbers were presented as digits. The answer is positive because sentence comprehension was better with Arabic digits than with number words. This result extends that previously observed when people comprehend numbers in isolation (e.g., number comparison task, Macizo & Herrera, 2008). There is a large amount of experimental work in number cognition demonstrating the existence of a common, notation-independent, magnitude representation which is accessed irrespective of number format. For instance, the distance effect (i.e., the time to compare two numbers is an inverse function of the numerical distance between them; Moyer & Landauer, 1967) which is carried out on internal semantic representations that reflect magnitude and quantity relations among numbers, is virtually identical for digits and number words (Buckley & Gillman, 1974). In addition, there is semantic facilitation in the processing of target numbers regardless the format of related numbers previously presented (e.g., cross-notational semantic priming, Koechlin, Naccache, Block, & Dehaene, 1998). Thus, magnitude information seems to be notation-independent at least for symbolic quantities (e.g., digits, number words). When differences are found across number formats, they are generally ascribable to encoding processes (Nöel & Seron, 1992)¹. The encoding differences between digits and number words might be determined by the frequency of occurrence

of numbers in these two formats (Hurford, 1987) and/or by the number of processing stages needed to access magnitude information. McCloskey and Macaruso (1995), indicated that comprehension of alphabetic written number words involves (a) identification of individual letters, (b) identification of the word as a whole, and (c) retrieval of the word's meaning; whereas the comprehension of logographic digits involves (a) identification of the digit and (b) retrieval of the digit's meaning. The additional processing stage in verbal number processing might produce weaker semantic activation as compared to the processing of Arabic digits. This possible explanation remains to be explored in future research. In any case, the results of the present study indicate that encoding differences in the processing of digits and verbal numbers exert an influence beyond that level such as sentence comprehension.

The second question of the present study was to evaluate whether comprehension of sentences that contain numerical information would benefit from the introduction of world knowledge. Previous studies have observed that reading comprehension rely on rich prior knowledge about real life and that its use enhances readers' comprehension (e.g., Kintsch & Franzke, 1995). The present study demonstrates that the benefit associated to the use of prior knowledge in reading comprehension extends to the case of magnitude information.

It might be argued that participants used their prior knowledge about quantities (what is usually larger, bigger, etc. in the world) to create shallow representations which lead them to comprehend correctly the biased sentences (the good-enough approach; Ferreira, Ferraro, & Bailey, 2002; Patson, Darowski, Moon, & Ferreira, 2009). Ferreira and colleagues argue that semantic representations of sentences are sometimes not complete, detailed and accurate but they are shallow representations that generally suffice to perform a comprehension task. For example, when asked "how many animals of each sort did Moses put in the ark?" people tend to respond "two" without noticing that it was Noah who put the animals in the ark instead of Moses (the Moses illusion, Erickson & Mattson, 1981). The Moses illusion suggests that readers' comprehension can be quite shallow but well enough to know what they are been asked. These shallow representations directly refer to heuristics or "short-cuts" that readers use to correctly understand sentences in absence of a full lexical and syntactic processing (Ferreira, 2003). In the biased condition of the current study, world knowledge about quantities and literal number information oriented to the same sentence interpretation. Therefore, it might be possible that participants created sentence meanings based on their prior knowledge only because it was good enough to perform the comprehension task without processing deeply the numerical information. An indirect source of evidence for this tentative explanation comes from studies in which lexical effects typically found with single words (e.g., repetition effect, associative priming, etc.) disappear or become weaker when these words are embedded in sentences (see

¹ Although the majority of researchers defend that differences across numerical formats are due to encoding processes, there are authors suggesting that magnitude representation might be modulated by the format in which numbers are presented (see Cohen-Kadosh & Walsh, 2009; for a discussion on this topic).

Ledoux, Camblin, Swaab, & Gordon, 2006, for a review). However, this hypothesis might predict no differences based on the numerical format of quantities embedded in biased sentences. Thus, if participants relied more on prior knowledge than on number processing to comprehend biased sentences the effect of numerical format might be attenuated. On the contrary, sentences were better understood with digits than with number words in both biased and unbiased sentences. In addition, although the results of this experiment indicated that participants benefited from the use of prior knowledge, this knowledge did not suffice to comprehend unbiased sentences. Therefore, participants might be using both world knowledge and numerical information to comprehend the sentences in the current study. Further re-

search is needed to explore deeply this question in the context of number processing and the use of world knowledge during sentence understanding.

To conclude, the present study shows that comprehension of numerical information in sentence context is enhanced by using Arabic digits and by connecting information with people's prior knowledge.

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