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NoA's ark: Influence of the number of associates in visual word recognition

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The main aim of this study was to explore the extent to which the number of associates of a word (NoA) influences lexical access, in four tasks that focus on different processes of visual word recognition: lexical decision, reading aloud, progressive demasking, and online sentence reading. Results consistently showed that words with a dense associative neighborhood (high-NoA words) were processed faster than words with a sparse neighborhood (low-NoA words), extending previous findings from English lexical decision and categorization experiments. These results are interpreted in terms of the higher degree of semantic richness of high-NoA words as compared with low-NoA words.

How easily and how fast visually presented words are recognized depends on a large array of lexical properties (see, e.g., Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004). Length, frequency, orthographic neighborhood, and concreteness (among other factors) are commonly controlled for in experiments aimed at uncovering the mechanisms of visual word recognition (hereafter, VWR). In the present article, we propose that NoA—number of associates—influences the core process of VWR and, consequently, should be routinely controlled for in experiments exploring word processing (see Carreiras, Perea, & Grainger, 1997, for a parallelism regarding orthographic neighbors).

In order to assess the relative influence of different variables in VWR, Balota et al. (2004) performed regression analyses on a huge pool of naming and lexical decision data. Of special relevance for the present study was the inclusion of a meaning-based variable that they called *Nelson's set size*, defined as the number of different first associates produced by a group of participants who completed a free-association normative study (Nelson, McEvoy, & Schreiber, 1998). It has been suggested that associatively related words become activated in the course of perceiving a single word (see, e.g., Nelson, McKinney, Gee, & Janczura, 1998), and are therefore expected to have an impact on that word's recognition. If this is so, it could be expected that words with a larger number of associates (e.g., *fog*, with up to 25 associates) would receive more activation from these associates than words with a low number of associates (e.g., *fuel*, with 5 associates). In fact, Balota et al. (2004) showed that there was an influence of the number of associates (NoA), but that this was restricted to lexical decision tasks, with scarce influence in word naming.

Subsequent English studies by Buchanan, Westbury, and Burgess (2001); Yates, Locker, and Simpson (2003); Locker, Simpson, and Yates (2003); and Pexman, Hargreaves, Edwards, Henry, and Goodyear (2007) also explored the influence of this measure in VWR. Buchanan et al. showed that high-NoA words (words with a dense set of associates in a free-association test) were processed faster than low-NoA words in a lexical decision task. Hence, their results coincide with those of Balota et al. (2004). Yates et al. replicated these results and showed that this effect can be extended to English pseudohomophones: A nonword that sounds like a real word activates the semantic neighborhood of the real word, and this semantic neighborhood affects the processing of the pseudohomophone. In another lexical decision experiment, Locker et al. showed that NoA can also affect the processing of ambiguous words. More recently, Pexman, Hargreaves, Edwards, et al. (2007) acquired fMRI data from participants who were asked to categorize high- and low-NoA words as being edible or drinkable. Their results showed a reduced cortical activation for high-NoA words in the left inferior frontal gyrus. These results were accompanied by a behavioral effect, with high-NoA words categorized faster than low-NoA words.

At this point, it seems clear that NoA is a variable that consistently affects lexical decision times for En-

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glish words. However, it is not clear whether NoA has an impact on the different tasks commonly used in VWR research and whether NoA affects word processing in languages different from English. In order to shed light on these issues, we conducted four experiments in Spanish using different tasks: lexical decision, reading aloud, progressive demasking, and online sentence reading. Considering NoA as a lexical–semantic variable, its influence should be evident even in tasks with a low semantic component (such as naming or perceptual identification). However, if the NoA effect is restricted to semantic categorization and lexical decision tasks (Buchanan et al., 2001; Locker et al., 2003; Pexman, Hargreaves, Edwards, et al., 2007; Yates et al., 2003), the impact of this variable will be limited. It should be stressed that since all the previous insights about the NoA effect have been found in English, cross-linguistic support for this effect is recommended in order to draw stronger conclusions about its influence.

EXPERIMENT 1: Lexical Decision

Method

Participants. Twenty-six undergraduates from the University of La Laguna completed this experiment for course credit.

Materials. We selected 50 high-NoA words and 50 low-NoA words from the Spanish association norms (Fernández, Díez, Alonso, & Beato, 2004[1]). These words were matched by frequency, number of letters, phonemes, syllables, orthographic and phonological neighbors, and concreteness (see Table 1). A set of 100 nonwords was created by changing 3–4 letters from these words to make the lexical decision possible.

Procedure. The experiment was run individually using DMDX software (Forster & Forster, 2003) on a PC-compatible computer that was linked to a CRT screen located in a soundproof cabin. Each trial consisted of the presentation of a fixation point for 500 msec, followed by the presentation of a letter string in lowercase Courier New 12-pt. font. Participants were instructed to press one labeled button on the keyboard to indicate that the string presented formed a real Spanish word, and to press another one to indicate that the string did not form a real word.

Results

Response latencies beyond or above the 250–1,500 cutoff values (4.3% of the data) were excluded from the analyses. The *t* tests by participants and items showed that high-NoA words were recognized 38 msec faster than low-NoA words (Table 2) [$t_1(25) = 6.67, p < .001$; $t_2(98) = 2.08, p < .04$]. Similarly, high-NoA words were identified more accurately than low-NoA words, even though this effect was not significant in the item analysis [$t_1(25) = 2.39, p < .03$; $t_2(98) = 1.72, p = .09$].

EXPERIMENT 2: Naming

In line with previous English studies, results from Experiment 1 confirmed that in a Spanish lexical decision task, high-NoA words are processed faster than low-NoA words. Experiment 2 was designed to test the NoA variable in a word-naming paradigm. Balota et al. (2004) failed to find an influence of NoA on word naming latencies in their regression analyses, but Pexman et al. (2007) examined this issue with data taken from the English Lexicon Project (Balota et al., 2002) and found a reading benefit for high-NoA words. However, it should be noted that these post hoc analyses were carried out on words that were not controlled on initial phoneme, which is a key factor that affects naming latencies. High-NoA words could be expected to be read faster than low-NoA words as a consequence of the greater feedback from the semantics to the phonological level (Pexman & Lupker, 1999). However, this feedback from semantics to phonology has been recently questioned (Reimer, Lorsbach, & Bleakney, 2008). Therefore, it could be the case that the effectiveness of NoA may not be evident in a reading-aloud task.

Table 1
Mean Characteristics and Standard Deviations of the Stimuli Used in the Four Experiments, With Results of the Statistical Comparisons for Each Variable

	Frequency		Syllables		Phonemes		Letters		Concreteness		Orthographic Neighbors		Phonological Neighbors		NoA	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Experiments 1 and 3																
Low NoA	12.4	10.9	3.1	0.9	7	2	7.2	1.8	4.6	1.7	1.2	1.5	2	2.2	5.6	1.3
High NoA	13	15.5	2.9	0.8	6.6	1.6	6.9	1.5	4.3	2.8	1.2	2	1.9	2.2	34.4	7.4
t tests	$t(49) = .21$		$t(49) = 1.16$		$t(49) = 1.34$		$t(49) = 1.20$		$t(49) = .73$		$t(49) = .62$		$t(49) = .63$		$t(49) = 27.13$	
	$p = .83$		$p = .25$		$p = .19$		$p = .24$		$p = .47$		$p = .54$		$p = .53$		$p < .001$	
Experiment 2																
Low NoA	28.6	36.7	2.7	0.7	6.1	1.6	6.1	1.5	4.8	1.1	2.4	3.5	3.5	5.2	8.1	2.0
High NoA	31.0	42.4	2.6	0.7	6.0	1.7	6.1	1.7	5.6	1.1	2.4	3.9	3.9	5.7	39.6	9.1
t tests	$t(39) = .56$		$t(39) = .83$		$t(39) = .55$		$t(39) = .57$		$t(39) = 3.25$		$t(39) = .24$		$t(39) = .89$		$t(39) = 20.88$	
	$p = .58$		$p = .41$		$p = .58$		$p = .57$		$p < .01$		$p = .81$		$p = .38$		$p < .001$	
Experiment 4																
Low NoA	21.6	26.9	2.7	0.6	6.0	1.4	6.2	1.2	5.1	0.9	2.1	3.1	3.2	4.2	7.2	1.9
High NoA	24.4	22.7	2.6	0.8	5.9	1.6	6.1	1.6	5.4	0.9	2.6	2.8	4.0	4.3	30.0	9.0
t tests	$t(39) = .56$		$t(39) = 1.50$		$t(39) = 1.31$		$t(39) = 1.18$		$t(39) = .52$		$t(39) = 1.04$		$t(39) = .66$		$t(39) = 27.99$	
	$p = .57$		$p = .14$		$p = .19$		$p = .24$		$p = .61$		$p = .30$		$p = .51$		$p < .001$	

Table 2
Summary of the Results in the Four Experiments

	High NoA	Low NoA	Difference (High − Low)
	Experiment 1		
Lexical decision times	752	790	38
Error rates in %	2.2	4.0	1.8
	Experiment 2		
Reading times	498	527	29
Error rates in %	0.7	0.8	0.1
	Experiment 3		
Identification times	1,477	1,622	145
Error rates in %	0.5	0.7	0.2
	Experiment 4		
First fixation duration	214	220	6
Gaze duration	244	265	21
Total time	284	307	23
Regressions (in %)	11.2	11.5	−0.3
Skipping rate (in %)	9.6	7.9	−1.7

Note—Nonwords in Experiment 1 were identified with a mean reaction time of 857 msec and with a mean error rate of 5.1%.

Method

Participants. Twenty-six different participants from the same population took part in this experiment.

Materials. A set of 40 high-NoA words and 40 low-NoA words was selected. These words were matched in all the above-mentioned variables (see Table 1) and in a pairwise manner for initial phonemes (e.g., high-NoA: *nube*, /'nuβe/, "cloud"; low-NoA: *nuca*, /'nuka/, "nape").

Procedure. Participants were instructed to read aloud the words that were presented in the center of the screen after a fixation cross that remained for 500 msec. Stimuli presentation and reading time collection were carried out using DMDX software. Resulting data were analyzed with the CheckVocal software (Protopapas, 2007).

Results

Responses beyond the 250- to 1,500-msec cutoff values (0.7% of the data) were excluded from the latency analyses. Results from the *t* tests revealed that high-NoA words were read 29 msec faster than low-NoA words [$t_1(25) = 4.82$, $p < .001$; $t_2(78) = 2.35$, $p < .03$]. No significant differences were found in the error-rate analyses.

EXPERIMENT 3: Progressive Demasking

In Experiment 3, we tested NoA under a progressive demasking task, which is an online perceptual identification task (Dufau, Stevens, & Grainger, 2008). This task has an increased sensitivity to lexical variables as compared with a lexical decision task. In fact, word frequency and orthographic neighborhood have been found to show increased effects in this task. Thus, considering NoA as a lexical–semantic variable, we expected high-NoA words to be recognized faster than low-NoA words, under the assumption that semantically richer words (high-NoA words) are accessed and processed faster. Due to the high semantic richness of high-NoA words, the VWR system is expected to settle faster into a stable pattern of activation, leading to a faster identification of these words.

Method

Participants. A different group of 30 students completed this experiment for course credit.

Materials. The same words as those in Experiment 1 were used.

Procedure. The experiment was run using the PDM software (Dufau et al., 2008). Trials were composed of target–mask pairs that were consecutively repeated several times. In each trial, the total display time of the stimulus was held constant at 210 msec, but the ratio of the target and mask display durations was progressively increased in cycles. In the first cycle, the mask display duration was much longer than the target one (195 and 15 msec, respectively). In the following cycles, the mask display duration decreased, whereas the target display duration increased in a constant way. After the 13th cycle, only the target word was presented. Participants had to press the spacebar when they had recognized the word, and then type it. Reaction times (RTs) were measured from the initial display of the mask in the first cycle to the buttonpress.

Results

RTs shorter than 300 msec or longer than 3,500 msec (0.2% of the data) were excluded from the analysis. The results of the *t* tests showed that high-NoA words were identified much earlier (145 msec) than low-NoA words [$t_1(29) = 11.35$, $p < .001$; $t_2(98) = 4.94$, $p < .001$]. No significant differences were found in the error-rate analyses.

EXPERIMENT 4: Sentence Reading

Finally, in Experiment 4, we tested high- and low-NoA words that were embedded in nonpredictive sentences while participants' eye movements were recorded. Studies testing semantic variables in eye movements are scarce and inconclusive; however, considering that other well-known lexical variables have been shown to affect both first-pass and second-pass measures (Hyönä & Olson, 1995; Inhoff & Rayner, 1986), we tentatively expected a similar influence of NoA on eye-movement patterns.

Method

Participants. Twenty-six different undergraduates completed this experiment for course credit.

Materials. We created 40 pairs of sentences that differed only in a single word, which could be either a high-NoA word (Example 1A) or a low-NoA word (Example 1B). These words were matched in other variables (Table 1). The sentences were 9–10 words long and never occupied more than a single line on the screen. The critical word was presented at the sixth position.

(1A) Tengo que reconocer que aquella *charla* no me gustó.
I have to admit that I didn't like that *talk*.

(1B) Tengo que reconocer que aquella *disputa* no me gustó.
I have to admit that I didn't like that *dispute*.

A cloze test conducted with a pool of 20 students established that the critical words were equally unpredictable in the sentence context (mean cloze probability for high-NoA words was .02±.13, and for low-NoA words it was .02±.05). A plausibility questionnaire was also conducted with 24 different participants, and the results showed that high- and low-NoA words were equally plausible regarding the preceding context (high NoA, $M = 6.1 \pm 0.3$; low NoA, $M = 6.0 \pm 0.3$; in a 1–7 scale, in which "7" referred to a totally plausible sentence). Two lists were created following a counterbalanced design so that each sentence appeared only once in each list, but each time with a different critical word (high NoA or low NoA).

Procedure. The eye movements of the participants were recorded with an EyeLink II eyetracker that was manufactured by SR Research Ltd. (Canada). Registration was binocular, although only data from the right eye were analyzed. After the calibration and validation processes, participants read four practice sentences. Each trial started with the presentation of a left-aligned fixation point (coinciding with the location of the first letter of each sentence) that also served to automatically correct possible calibration drifts. Participants were instructed to read for comprehension and to press one button in a gamepad as soon as they finished reading the sentence. Comprehension questions were displayed after 25% of the sentences (mean accuracy of response was 93.1%).

Results

Fixation analyses were performed on the target words (excluding fixations shorter than 80 msec and longer than 800 msec). Separate ANOVAs for participants and items were conducted based on a 2 (NoA: high, low) × 2 (list: 1, 2) design. List was included as a dummy variable. We will only refer to the two measures that reflected a significant effect: *gaze duration* (the sum of the durations of the fixations made on the target word before the eyes leave that word) and *total time* (the sum of the duration of all the fixations on the word, including fixations from regressions). The analyses of the rest of the measures showed no significant differences between conditions (Table 2). The gaze duration for high-NoA words was 21 msec shorter than that for low-NoA words [$F_1(1,24) = 8.97$, $p < .01$; $F_2(1,38) = 8.63$, $p < .01$]. The total time for all the fixations on high-NoA words was also shorter (23 msec shorter) than the total time of fixation on low-NoA words [$F_1(1,24) = 5.10$, $p < .04$; $F_2(1,38) = 5.04$, $p < .04$]. Hence, NoA exerted an influence not only in measures of rereading behavior (e.g., total time), but also in first-pass reading measures (e.g., gaze duration).

GENERAL DISCUSSION

The factors of frequency, length, orthographic neighborhood, and concreteness, among others, have been consistently identified as affecting VWR. In this study, we investigated how the NoA of a given word influences VWR. Our results revealed that high-NoA words were identified faster than low-NoA words in a lexical decision task (Experiment 1). The same pattern of results was obtained when participants named high- and low-NoA words, confirming that increasing the NoA of a word speeds up its reading time (Experiment 2). In a progressive demasking paradigm, results showed that high-NoA words were identified much faster than low-NoA words (Experiment 3). Finally, eye-movement measures obtained during silent sentence reading showed that participants made shorter fixations on high- than on low-NoA words (Experiment 4).

It has been shown that words with small sets of associates (low-NoA words) are recalled faster and more accurately than words with larger associative sets (high-NoA words; Nelson, McKinney, & McEvoy, 2003). Previous evidence from VWR research has also shown that a measure of lexical–semantic richness, such as NoA, has an impact on the speed and accuracy with which words are processed (Buchanan et al., 2001; Locker et al., 2003; Pexman et al., 2007; Yates et al., 2003). However, this evidence was obtained exclusively in lexical decision and semantic categorization tasks, and it was confined to experiments testing English speakers. The present results confirm that the influence of NoA can also be extended to different tasks and languages. Importantly, the NoA effect does not seem to be restricted to tasks with a medium-high semantic component (e.g., lexical decision, or semantic categorization); it is also noticeable in tasks with a less demanding semantic component (e.g., reading aloud or perceptual identification). In addition, NoA is seen to exert an important influence on participants' eye-movement patterns, with shorter fixations on high-NoA words. This is a striking result because, as stated in the introduction to Experiment 4, evidence of semantic variables influencing eye movements is inconclusive (see Rayner, 1998).

We interpret the advantage of high-NoA words in terms of an increased activation of these words, which is a direct consequence of their semantic richness. Such an enhanced activation can be accounted for by different models. For instance, classical network models of semantic memory (that assume that the degree of activation of a node is a monotonic function of the amount of excitation reaching that node from neighboring nodes) could easily account for the NoA effects. One of the dominant models of semantic processing—spreading activation—seems especially suited to account for these results, since association is the underlying principle of the network (Collins & Loftus, 1975). In this model, concepts are linked and interconnected in an associative network in conceptual space. Activation spreads along the associative nodes when a concept is activated, and, because of the bidirectional connections, high-NoA words would spread and receive more activation than low-NoA words. Models based on distributed representations of orthography, phonology, and semantics can also account for these outcomes (see, e.g., Plaut, 1997; Seidenberg & McClelland, 1989). As a result of the increase in measures of familiarity derived from semantic activation of high-NoA words (e.g., the *semantic stress*; Plaut, 1997; Plaut & Booth, 2000), they are processed faster. Similarly, Locker et al. (2003) and Yates et al. (2003) interpreted the recognition advantage of high-NoA words in lexical decision tasks within the framework of a fully interactive model in which the orthographic, phonological, and semantic levels are interconnected and also have bidirectional excitatory connections (see, e.g., Pexman & Lupker, 1999). High-NoA words involve an enhanced semantic activation that "feeds back to the orthographic level and helps participants respond more quickly to these words than to words with weaker activation from the semantic level" (Yates et al., 2003, p. 857; see also Hino & Lupker, 1996). In a similar fashion, Pexman et al. (2007) have interpreted the NoA effect in line with Plaut and Shallice's (1993) proposal: As a consequence of the number of semantic units (semantic richness) involved in a representation, for high-

NoA words, "the system is able to settle faster into a stable pattern of activation" (p. 401). Hence, the facilitative NoA effect could be due to the fact that high-NoA words activate more lexical–semantic information, leading to higher levels of global lexical activation (consequently modifying the activation threshold of those words; see Holcomb, Grainger, & O'Rourke, 2002).

Our results are in line with an increasing body of literature indicating that numerous measures of semantic richness have a clear impact on VWR (see Pexman, Hargreaves, Siakaluk, Bodner, & Pope, 2008, for a review). Future research should be aimed at exploring the relative influence of each measure of semantic richness of a word on its recognition (e.g., number of associates, number of features, number of semantic neighbors, semantic distance, or contextual dispersion). For instance, Mirman and Magnuson (2008) showed that association-based semantic neighborhood measures were as good predictors of RTs as were measures based on shared features or co-occurrence. Interestingly, very close semantic neighbors (with greater feature overlap) produced slower RTs in a semantic categorization task. In consequence, feature-based measures and NoA might be reflecting the influence of different relationships in semantic memory. Ongoing work in our laboratory is aimed at clarifying facilitative and inhibitory influences of the above mentioned measures of semantic richness. The influence of uncontrolled and potentially confounding variables should also be explored in upcoming research. For instance, it has been shown that the age of acquisition (AoA) is a variable that affects lexical decision and word-naming times (see Cortese & Khanna, 2007, for a review). Unfortunately, AoA norms were not available for most items used in our experiments. However, we asked 20 participants to rate all of these words according to a 1–7 AoA typical scale.[2] On average, high-NoA words were said to have been acquired earlier than low-NoA words (4.6 ± 1.1 vs. 2.9 ± 0.9). This is not a surprising finding, according to the view that "earlier acquired words provide a structure in semantic memory upon which later words build, thus forming a semantic locus" (Cortese & Khanna, 2007, p. 1073). In order to explore the relative influence of AoA and NoA on the results observed, we performed a stepwise hierarchical regression analysis on the RTs from Experiments 1, 2, and 3, controlling for all the other variables (NoA and AoA were included in the last step). Altogether, an adjusted R^2 value of .70 was obtained, and NoA was shown to have a significant influence, even when controlling for the other variables (standardized regression coefficient $\beta = -.14$, $p < .01$). Contrarily, AoA was shown to have a negligible influence ($\beta = -.03$, $p > .50$).

Taking into account that in a variety of tasks representative of VWR, as well as in different languages, NoA has been shown to be a variable that strongly influences the speed with which a word is recognized, processed, read, and recalled, we propose that this variable deserves future research and attention.

AUTHOR NOTE

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NOTES

1. Fernández et al. (2004) presented participants with a list of words and asked them to provide a single response that was meaningfully related (see also Nelson et al., 1998). We obtained the number of responses to a given word across participants in order to define that word's NoA (following the *Nelson's set size* definition).

2. We thank Michael Cortese and an anonymous reviewer for pointing this out.

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