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Associative and orthographic neighborhood density effects in normal aging and Alzheimer's disease

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Abstract

A group of patients with Alzheimer's disease and a group of healthy elderly controls were tested with a lexical decision task that included words with dense or sparse orthographic and associative neighborhoods, to investigate whether there is automatic orthographic and semantic activation of related representations in these populations, similar to that found with younger samples. While some studies support the idea of deteriorated connections in semantic networks in Alzheimer's disease, other studies propose that the automatic spread of activation at lexico-semantic levels remains intact and that intergroup differences are a consequence of impaired retrieval or attentional deficits. In this study, participants responded to words with dense orthographic and associative neighborhoods faster than to words with sparse neighborhoods, providing evidence in favor of a preserved automatic spread of activation through intact orthographic and semantic representations. Furthermore, no differences were found between the two groups regarding the magnitude of the effects, even though control participants responded significantly faster than patients.

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When a single word is read, other stored words that share orthographic or semantic features with it also become partially activated due to the automatic spread of activation (e.g., Forster, 1987; Grainger 2008). The present study investigates how the automatic activation of neighboring lexical and semantic representations affects visual word recognition in a group of patients with Alzheimer's disease and in a control group of elderly individuals.

Coltheart, Davelaar, Jonasson and Besner (1977) characterized the orthographic neighborhood (N) of a given word as all the existing words that could be created by replacing one of its letters by another different one (e.g., *horse* and *house*). Words can have no or few neighbors (low-N words) as well as many neighbors (high-N words; see Andrews, 1992, 1997). Most published experiments show that high-N words produce facilitative effects on lexical decision, especially when low-frequency words are used: Participants classify high-N words as words faster and more accurately than low-N words (e.g., Carreiras, Perea & Grainger, 1997; Pollatsek, Perea & Binder, 1999; Sears, Hino & Lupker, 1995).

A similar assumption holds for semantically related words. When accessing the meaning of a written word, other semantically related words are co-activated (Pexman et al., 2007; Plaut & Shallice, 1993). One of the measures of semantic richness that has been shown to effectively modulate word recognition is the Number of Associates (NoA). NoA is 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). One can find words with sparse associative neighborhoods (low-NoA words), and words with dense associative neighborhoods (high-N words). In the lexical decision task, there is a great deal of evidence showing that high-NoA words are recognized faster and more accurately than low-NoA words (e.g., Balota et al., 2004; Buchanan, Westbury & Burgess, 2001; Locker, Simpson & Yates, 2003; Yates, Locker & Simpson, 2003; see Duñabeitia, Avilés & Carreiras, 2008, for review).

There seems to be a similar process for these two variables (N and NoA) at the lexical stage: automatic global lexical activation (Grainger & Jacobs, 1996). In terms of activation-based models (e.g., Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981), the orthographic representations of the target word send activation to the matching letter units of that word's orthographic neighbors, while these, in turn, send feedback activation to the orthographic features. As a consequence of this cyclical process, the word likelihood of the target increases (see Balota & Chumbley, 1984). Considering that high-N words have extensive orthographic overlap with many other words, their global lexical activation level is higher. Similarly, the facilitation observed in lexical decision for high-NoA words can be also explained in terms of an increased level of activation. High-NoA words activate more associated representations than low-NoA words, leading to higher levels of automatic global lexical activation (see Hino & Lupker, 1996; Yates et al., 2003). Thus, in tasks in which global lexical activation is beneficial (e.g., lexical decision), N and NoA produce similar effects. For both high-N and high-NoA words, the system is able to settle faster into a stable representation and the word likelihood of these strings is higher[1].

In the present study, we explored the influence of these two indexes in a group of healthy aged individuals and in a group of patients with Alzheimer's disease (AD).

[1] This idea was recently confirmed in an ERP experiment in which both N and NoA-density were manipulated (Müller, Duñabeitia & Carreiras, 2008). Our results showed a N400 modulation depending on the number of orthographic neighbors of a word, and also a N400 modulation as a consequence of the number of associative neighbors (see also Holcomb, Grainger, and O'Rourke, 2002). The topographical distribution, however, was more anterior for the NoA than for the N-size effect.

AD is the most common form of dementia and there is consensus that these patients perform poorly on semantic tasks as compared to control healthy individuals (e.g., Hodges & Patterson, 1995; Rogers, Ivanoiu, Patterson & Hodges, 2006). However, there is not agreement on the reasons underlying this impairment. On the one hand, some authors propose that the semantic memory deficits are a consequence of the neuropathology of AD (e.g., Hodges, Salmon & Butters, 1992), so that the automatic spread of activation in semantic networks is impaired in this type of patients (e.g., Bell, Chenery & Ingram, 2001). On the other hand, other authors propose that the semantic store is relatively unaffected in AD and that semantic impairments take place as a consequence of dysfunctional semantic access or retrieval (e.g., Bayles et al., 1991; Nebes & Brady, 1990; Ober, Shenaut & Reed, 1995). Thus, according to the access or retrieval deficit hypothesis, the integrity of semantic representations remains intact in AD, and differences observed between AD patients and controls in tasks with a clear semantic component (e.g., Cherktow et al., 1994; Giffard et al., 2002; see Giffard et al., 2003, for review) reflect the combination of a generalized cognitive slowing process (Bush, Allen, Kaut & Ogrocki, 2007; Nebes & Brady, 1992) together with attentional problems (Chenery, Ingram & Murdoch, 1994; Shenaut & Ober, 1996). According to this view, the automatic spread of activation should be intact in groups of patients with AD. Therefore, high and low-NoA words can help to shed some light on the integrity of the semantic representations and the way in which words automatically activate semantically related concepts in the elderly and patients with AD. To our knowledge, until now the only study dealing with a similar manipulation is the recent work by Balota et al. (2004) that tested young and older healthy adults in a naming and lexical decision task. Among other variables, the authors included NoA-density in their regression analyses (termed as *Nelson's set size*). They concluded that NoA produced a similar facilitation effect for both groups in the lexical decision task. Therefore, considering that the NoA effect is well-established also for healthy older readers, a direct comparison between the lexical decision performance of patients with AD and healthy matched controls seems suitable to uncover the underlying status of the automatic connections in semantic networks in dementia.

Even though other aspects of patients' word processing have received less attention, some empirical evidence suggests that sub-lexical representations are intact in AD and the elderly. For instance, Kavé and Levy (2003) showed that morphemic processing is unaffected in AD. Similarly, Carreiras, Baquero and Rodríguez (2008) showed that syllabic processing at a structural level is not degraded in AD and in older controls. To our knowledge, the influence of N-density, as a marker of sub-lexical processing, has not been explored in AD yet. If it is the case that processing of sub-lexical representations is not impaired in this pathology, patients with AD should exhibit a similar N-size effect to that of control readers, since orthographic neighborhood effects depend on a correct processing of strings at letter level. However, it has been shown that a written word gives access to its neighbors' semantic representations. As a consequence of the automatic spread of activation, when a word like *leotard* is presented the semantic category "animal" becomes activated due to that word's orthographic neighbor *leopard* (see Duñabeitia, Carreiras, Perea, 2008; Rodd, 2004). Thus, it could also be the case that, despite the allegedly preserved sub-lexical processing, as a consequence of a breakdown in semantic representations in AD the effect of N-size varies between healthy older adults and patients with AD. In the study by Balota et al. (2004), N-density was also incorporated and their results showed that this factor produced a tendency for an inhibitory effect in the group of older adults when they performed a lexical decision task. Thus, high-N words were responded to more slowly than low-N words. This is a very surprising effect for two main reasons. First, in a previous study exploring a more restricted set of variables, Spieler and Balota (2000) showed the N-size effect facilitated naming latencies in a group of older readers. These two results are somehow incompatible, and since they are the only pieces of evidence available regarding the influence of orthographic neighborhood in the elderly, no clear conclusion can be drawn so far[2]. Second, from a theoretical perspective, and considering that many researchers believe that the changes in word processing associated with normal healthy aging do not represent a qualitative change (see also Carreiras et al., 2008; Davidson, Zacks, & Ferreira, 2003; Duñabeitia, Marín, Avilés, Perea & Carreiras, in press; Rayner et al., 2006; Waters & Caplan, 2005), the N-size effect could be expected to be similar (both in magnitude and direction) for young and older readers. The present study will thus also help to establish more clearly the influence of N-size in normal aging.

In sum, in this study we explored the level of integrity of the semantic memory system and whether the automatic spread of activation among interconnected word representations is intact or impaired in AD and normal aging, through the investigation of the influence of N and NoA (as two indexes of an automatic lexico-orthographic and lexico-semantic spread of activation) in a lexical decision task with the presentation of written words in isolation.

Method

Participants. Forty adults completed this experiment. All were native Spanish speakers. The group of patients with AD was composed of 20 patients (15 females) recruited at the Memory Clinic of the San Ignacio hospital, Bogotá. All patients met the NINCDS-

[2] Moreover, it should be noted that the conclusions from these two studies were taken from multiple hierarchical regression analyses conducted over a huge pool of data taken from a set of words that were not matched in terms of any relevant variables.

ADRDA research diagnostic criteria for probable AD. They had no other associated pathology and had undergone a battery of neurological and neuropsychological tests that included assessment of attention, memory, verbal fluency and reasoning skills. The patients' Mini-Mental Status Exam scores ranged from 16 to 27 (mean: 23.3±3.4), and their mean scores in the Global Deterioration Scale ranged from 3 to 4 (mean: 3.7±0.5). Patients' age ranged from 60 to 84 years (mean: 72.3±6.9). These participants had completed a mean of 12.6 (±5.4) years of formal education. The group of control participants was composed of 20 persons (11 females), recruited from seniors clubs in Bogotá. These participants underwent the same neuropsychological testing protocol. Their ages ranged from 63 to 81 years (mean: 72.2±5.7) and they had completed a mean of 12.7 (±5.1) years of education. The controls' MMSE scores ranged from 24 to 30 (mean: 28.1±1.8). None of them had neurological, psychiatric or cognitive impairments. No statistical differences were obtained in any of the t-test performed on the characteristics of the two groups (all ps>.95), except for that on the MMSE and GDS scores (both ps<.001). All participants from both groups signed consent forms.

Materials. A total of 192 Spanish words were used. Half of these words formed the high and low-NoA groups. Words in the high-NoA group (e.g., "*rueda*", the Spanish for *wheel*) had a mean of 30.42 associates (range: 20-50), according to Fernández, Díez, Alonso and Beato (2004). Words in the low-NoA group (e.g., "*nido*", *nest*) had a mean of 6.40 associates (range: 2-9). The difference between these two NoA groups in terms of their number of associates was significant (p<.001). The other half of the words formed the high and low-N groups. Words in the high-N group (e.g., "*sopa*", *soup*) had a mean of 9.75 orthographic neighbors (range: 3-23), according to Davis and Perea (2005). All the words in the low-N group had no orthographic neighbors (i.e., hermit words; e.g., "*ídolo*", *idol*). The difference between these two N groups in terms of their number of orthographic neighbors was significant ($p<.001$). Words in the four different groups were matched for word frequency, number of letters and imageability (Table 1). Moreover, words in the high and low-NoA groups did not differ in terms of N (2.27/1.96; $p>.55$), and words in the high and low-N groups did not differ in terms of NoA (14.58/14.02; $p>.35$). A set of 192 nonwords were created to make the lexical decision possible. Nonwords were created by changing three or four letters from the target words (e.g., *"íduri"* from *"ídolo"*).

Insert_Table_1_here

Procedure. The experiment was run individually using DMDX software (Forster & Forster, 2003), which was installed in a portable computer. Each trial consisted of the presentation of a fixation point for 500 ms followed by a target letter string in lowercase. Each character of the targets had a width of 0.16 inches (note that Courier New font is a non-proportional font in which all letters occupy the same amount of space). Participants were instructed to make lexical decisions by pressing one out of two buttons in the keyboard. After every response or 4000 ms, the next trial started. Participants completed a practice session before the experiment. Items were randomized for each participant.

Results

Response latencies beyond or above 2 standard deviations (less than 4.9% of the word data) were excluded from the analyses. Response times and error rates associated with each experimental condition for each group of participants are displayed in Table 2. Separate ANOVAs were performed for the two types of density manipulations, N and NoA, following a 2 (Density: High, Low) x 2 (Group: Patients, Controls) design. ANOVAs by participants are presented with the effect sizes along with the confidence intervals of the effects.

Insert_Table_2_here

Orthographic neighborhood

Reaction times. The effect of Density was significant, with high-N words responded to 60 ms (±25) faster than low-N words, $F(1,38)=24.02$, $MSE=2977$, $p<.001$, partial $\eta^2=.39$. The effect of Group was significant, showing that patients with AD responded to words 224 ms (±182) more slowly than controls, $F(1,38)=6.19$, $MSE=161909$, $p<.02$, partial $\eta^2=.14$. Importantly, the interaction between the two factors was not significant (ps>.82). Follow-up pairwise comparisons showed that the Density effect was significant both in the AD patient group (a 57±44 ms effect; $t(19)=2.72$, $p<.02$, partial $\eta^2=.28$) and in the control group (a 63±26 ms effect; $t(19)=5.01$, $p<.001$, partial $\eta^2=.57$).

Error rates. The effect of Density was significant, showing that participants made 5.68% (±1.97%) more errors with low-N words than with high-N words, $F(1,38)=34.63$, $MSE=19$, $p<.001$, partial $\eta^2=.48$. The effect of Group was not significant ($p>.97$). Importantly, the interaction between the two factors was significant, $F(1,38)=4.90$, $MSE=19$, $p<.04$, partial $\eta^2=.11$. Follow-up pairwise comparisons showed that the Density effect was significant in the group of patients (3.54±2.29%), $t(19)=3.22$, $p<.01$, partial $\eta^2=.35$, but that the Density effect was of higher magnitude in the group of controls (7.81±3.31%), $t(19)=4.93$, $p<.001$, partial $\eta^2=.56$.

Number of Associates

Reaction times. The effect of Density was significant, with high-NoA words responded to 47 ms (±23) faster than low-NoA words, $F(1,38)=16.80$, $MSE=2634$, $p<.001$, partial $\eta^2=.31$. The effect of Group was also significant, with patients with AD responding 241 ms (±195) more slowly than controls, $F(1,38)=6.27$, $MSE=185561$, $p<.02$, partial $\eta^2=.14$. The interaction between the two factors was not significant ($p>.55$). Follow-up pairwise comparisons showed that the Density effect was significant both in the AD patient group (a 53±41 ms effect; $t(19)=2.67$, $p<.02$, partial $\eta^2=.27$) and in the control group (a 41±24 ms effect; $t(19)=3.58$, $p<.01$, partial $\eta^2=.40$).

Error rates. None of the effects were significant (all ps>.21).

General Discussion

The results of the present experiment were clear-cut. Patients with AD and healthy older participants showed a neighborhood density effect for both the orthographic and the associative neighborhood manipulations. Both groups responded faster to high-N and high-NoA words than to low-N and low-NoA words. A similar pattern of results emerged in the accuracy levels for the N manipulation. No differences were observed between the two groups in the magnitudes of the effects (none of the interactions with the Group factor were significant). Finally, healthy aged readers were faster than patients with AD but equally accurate.

The word-likelihood of a string increases as a function of the number of lexico-semantic representations that are co-activated by its processing, and an increased number of co-activated representations leads to higher levels of global lexical activation (Grainger & Jacobs, 1996). Consequently, high-N and high-NoA words, due to their augmented word-likeliness and their lower activation thresholds are recognized faster. Even though this has been consistently demonstrated in healthy young adult samples (e.g., Buchanan et al., 2001; Carreiras et al., 1997; Duñabeitia, Avilés & Carreiras, 2008), the evidence so far regarding the influence of orthographic and semantic richness in older readers and patients is scarce. In the present study, we have provided evidence for a preservation of the N and NoA-density effects in a group of patients with AD and in a group of healthy elderly readers. On the one hand, our results have shown that sub-lexical processing is preserved in the elderly and in AD, at least in what concerns letter units (according to the results from the N-size manipulation). Thus, visual word recognition processes are affected by orthographic overlap among words in these populations (see Andrews, 1997, for review). Furthermore, the present study has shown that automatic semantic processing of words is also preserved in the two groups (according to the results from the NoA-size manipulation). Automatic activation of semantically related words is present in these two groups, as in younger readers (see Duñabeitia, Avilés & Carreiras, 2008).

As we stated in the Introduction, there is contradictory evidence regarding the functionality and integrity of semantic memory in AD (e.g., Rogers et al., 2006). While some authors support the idea of an eroded semantic memory system (e.g., Hodges, Salmon & Butters, 1992), others claim that semantic representations remain unharmed in AD (Shenaut & Ober, 1996) and that under automatic conditions with restricted influence of attentional factors patients perform similarly to healthy controls (Chenery et al., 1994). The pattern of performance seen in this study is consistent with the idea of an automatic spread of activation at different processing levels which is intact in normal aging as well as in certain types of dementia. According to spreading activation models, concepts are interconnected within an associative network in conceptual space, and that activation spreads along the associative nodes (Collins & Loftus, 1975). Hence, if it were the case that patients with AD suffer from a degradation or erosion of semantic representations and semantic networks, this would imply that high-NoA words would be recognized in a similar way to low-NoA words, or at least that the magnitude of the difference between these would be much larger for the group of controls. However, this was clearly not the case, and both groups performed very similarly. In spite of this, it should be noted that the present results do not totally disallow certain sort of breakdown within the semantic memory system in AD for two reasons. First, it should be considered that the link between lexical retrieval and access processes and semantic storage processes is so tight that dissociating between them (i.e., isolating only one of the processes) is not simple (see Cloutman et al., in press). Second, the type of task that was used (lexical decision) has a low semantic component as compared to other visual word recognition tasks (e.g., semantic categorization), and therefore, subtle differences between groups could have been overlooked. Further research should be aimed at clarifying whether the same results can be obtained in tasks which tap more closely on semantics.

The results from the N-size manipulation (shorter response times for high-N words) coincide with previous evidence obtained with younger samples (e.g., Carreiras et al., 1997; Sears et al., 1995). It could be concluded from this that some aspects of sub-lexical processing are preserved in the elderly and in AD, as previously shown with other sub-word unit manipulations (e.g., Carreiras et al., 2008; Kavé & Levy, 2003). These results are in accordance with the view that changes in processing in healthy as well as in impaired aging are a consequence of a general cognitive slowing process that does not alter the basic underlying orthographic processes, and that when competing representations do not have to be inhibited, automatic activation of relevant orthographic representations persists intact, leading to greater levels of global lexical activation for high-N words and therefore a faster response (e.g., Grainger & Jacobs, 1996). It should be noted, however, that Balota et al. (2004) found an inhibitory effect of N-size in older readers in a set of hierarchical regression analyses. Considering that previous studies have shown that the N-size facilitative effect is more marked for low-frequency words and that the mean frequency of the words we used was low (see Materials), we selected a subset of words from the Balota et al. study that matched the characteristics of our materials, and sought for the mean lexical decision times of their older participants[3]. Interestingly, it turned out that their older adults responded faster to high-N words than to low-N words (a difference of more than 30 ms), as was the case in our study. Thus, it seems that under the appropriate frequency conditions and when a direct manipulation is carried out over a set of items controlled in terms of other variables, the N-size facilitative effect can be reproduced in older samples and in patients with AD.

Interestingly, we found longer latencies for patients than for control readers (approximately 230 ms). This response delay for the group of patients is consistent with the idea of a generalized cognitive slowing in AD (Nebes & Brady, 1992), and coincides with previous evidence showing that healthy older adults respond faster than patients with AD (e.g., Bush et al., 2007).

In summary, this study demonstrates that different orthographic and semantic richness measures have an influence on visual word recognition in the elderly and in AD. Furthermore, our results demonstrate an intact spread of activation through semantic networks in AD. These results will hopefully contribute to a better understanding and definition of the factors underlying the cognitive deterioration of these patients.

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[3] These data were taken from the item-level data from the Balota et al. study, available at http://www.artsci.wustl.edu/_dbalota/labpub.html. We selected those words in the same range of frequencies and orthographic neighbourhood as the present ones, ending with a group of 156 low-N words (mean frequency: 9.94±13.13; mean N: 0±0) and 1238 high-N words (mean frequency: 14.44±17.00; mean N: 10.10±4.26). Mean RT was 825 for low-N words, and 794 for high-N words, according to their data from the older group.

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Table 1

Characteristics of the materials used in the experiment (standard deviation is presented within parentheses).

	Type of Density			
	NoA		N	
	High	Low	High	Low
Frequency	14.05 (±17.41)	13.86 (±11.84)	14.41 (±12.15)	14.61 (±16.31)
Length	6.08 (±1.25)	6.08 (±1.13)	5.23 (±1.28)	5.75 (±0.67)
Imageability	5.88 (±0.70)	5.20 (±0.79)	5.30 (±1.04)	5.36 (±0.83)
NoA	**30.42** (±8.09)	**6.40** (±1.88)	14.58 (±3.07)	14.02 (±2.66)
N	2.27 (±3.21)	1.96 (±2.45)	**9.75** (±6.29)	**0.00** (±0.00)

Table 2

Mean reaction times (in ms) and percentages of errors (within parentheses) associated with each experimental condition.

	Type of Density				Difference (Low-High)	
	NoA		N			
	High	Low	High	Low	NoA	N
Patients	1168	1221	1119	1176	53	57
	(7.71%)	(6.04%)	(5.73%)	(9.27%)	(-1.67%)	(3.54%)
Controls	933	974	892	955	41	63
	(7.71%)	(6.88%)	(3.54%)	(11.35%)	(-0.83%)	(7.81%)
Total	1050	1097	1006	1066	47	60
	(7.71%)	(6.46%)	(4.64%)	(10.31%)	(-1.25%)	(5.68%)

Authors' Notes

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