Name agreement, frequency and age of acquisition, but not grammatical class, affect object and action naming in Spanish speaking participants with Alzheimer's disease

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Abstract

We investigated naming in native Spanish patients with probable Alzheimer’s disease using coloured line drawings of actions and objects, matched on several key psycholinguistic variables. The patients were less accurate than healthy controls but we found no significant evidence for an effect of grammatical class. Generalized linear mixed effects analyses indicated that patient naming accuracy was affected by lexical frequency and age of acquisition, and by the name agreement of the pictures. These observations support the view that, while the effect of grammatical class is not an important influence, accurate picture naming in dementia is determined by the impact of lesions on a lexico-semantic mapping structured by experience.

Keywords: Alzheimer; Objects; Actions; Picture naming; Frequency; Age-of-Acquisition

1. Introduction

Patients diagnosed with probable Alzheimer's disease (AD) experience a deterioration of their linguistic capacities that includes a lexical-semantic deficit evidenced in the prominence of semantic errors in spoken picture naming (Babarotto, Capitani, Jori, Laiacona, & Molinari, 1998; Cuetos, González-Nosti, & Martínez, 2005). Several previous studies have been conducted to investigate if the impairment of semantics affects object/noun or action/verb knowledge to the same extent, as indicated by performance in the picture naming task (e.g. Bowles, Obler, & Albert, 1987; Cappa et al., 1998; Druks et al., 2006). However, despite many reported studies, it remains rather uncertain whether there is a grammatical class effect on naming arising from the impairments consequent on dementia. The debate endures because the effect of grammatical class has wide significance for our understanding of the representation of lexical information in the brain yet observations have been inconsistent concerning the preservation of knowledge labelled by nouns or verbs.

We report an investigation in which we eliminated a number of possible methodological confounds to examine more stringently than has hitherto been possible the effect of grammatical class on picture naming by dementia patients. Our working theory at the outset of our study was that observations of the effect of grammatical class on patient naming have been inconsistent because naming accuracy is affected by a number of psycholinguistic factors and, in previous studies, several of these factors have not been sufficiently controlled in stimulus selection. Thus, our hypothesis was that we would find effects on naming associated with stimulus variation on item characteristics, in common with observations of naming in healthy adult and other populations, but that we would not find an effect of grammatical class.

Several studies have found that action naming is better preserved than object naming in AD patients (Bowles et al., 1987; Fung et al., 2001; Robinson, Rossor, & Cipolotti, 1999; Williamson, Adair, Raymer, & Heilman, 1998). The relative preservation of action naming has been explained to result from the distribution of cortical atrophy observed in the patients. Atrophy is thought to be present in different areas of the brain, mostly in the temporal lobe including the entorhinal cortex, the cingulate sulcus, the hippocampus, amygdala and perisylvian neocortex (Arnold, Hyman, Flory, Damasio, & Van Hoesen, 1991; Baron et al., 2001; Frisoni et al., 2002; Ishii et al., 2005; Scahill, Schott, Stevens, Rossor, & Fox, 2002). If we consider aphasic patients, though several exceptions have been described (see the exhaustive review by Druks, 2002), it is generally agreed that focal brain damage in the temporal lobe is related to problems in the production of nouns compared to verbs (Caramazza & Hillis, 1991; Daniele, Guistolisi, Silveri, Colosimo, & Gianotti, 1994; Miozzo, Soardi, & Cappa, 1994; Silveri & di Betta, 1997). Extrapolating from these aphasic data, if many dementia patients in a sample have sustained lesions largely involving the temporal lobe at the time of testing then one would expect to observe an impairment of the capacity to produce nouns with a spared ability to produce verbs.

In other studies, however, a preservation of object naming compared to action naming has been reported (Druks et al., 2006; Kim & Thomson, 2004; Masterson et al., 2007; Robinson, Grossman, White, & D'Esposito, 1996; White-Devine, Grossman, Robinson, Onishi, & Biassou, 1996). In some of these studies, the differences between the preservation of object and action naming are explained as the effect of the degradation of stored semantic knowledge that is commonly observed in AD patients (Hodges, Salmon, & Butters, 1992). In one of the most influential models of semantic knowledge, the Wordnet model (Miller & Fellbaum, 1991), semantic representations associated with verbs are sparser, more complex, and less redundant than the representations associated with nouns. Some authors (Robinson et al., 1999; Robinson et al., 1996) have explained that these characteristics make the semantic representations of verbs more vulnerable to an impairment when the semantic memory loss appears in AD patients.

Finally, we note that there are studies in which no significant differences have been found between object and action naming in dementia patients (Cappa et al., 1998). It should also be taken into account that, when significant differences have been recorded between action and object naming, in either direction, these differences have tended to be numerically small, with the exception of the single case study reported by Robinson et al. (1996). The inconsistency in the direction of previously reported differences in the accuracy of objects or action naming, coupled with at least one observation of a null effect of class, suggests that we should question whether grammatical class has an effect on naming over and above the effect associated with other factors.

In our view, the AD naming data are inconsistent in relation to the effect of grammatical class, in part, because insufficient control has been exerted over the psycholinguistic characteristics of the stimuli used. Most previous studies have employed lists of nouns and verbs matched on frequency (Cappa et al., 1998; Kim & Thomson, 2004; Robinson et al., 1999; Robinson et al., 1996). However, other critical characteristics have not been controlled. To date, the most strictly controlled studies of action and object naming are those reported by Druks et al. (2006) and Masterson et al. (2007), in which items from the different grammatical classes were pair-wise matched on age of acquisition (AoA). Also, in those studies, item selection was such that there were no significant differences in familiarity ratings between items of different grammatical class and overall only pictures with high name agreement were used. Nevertheless, Druks et al. (2006) and Masterson et al. (2007) reported significant differences between grammatical classes on the visual complexity of the pictures, as well as on the length and imageability of the picture names. Further, they noted that a difference in the frequency of noun and verb picture names approached significance. All these variables are known to be influential predictors of picture naming performance (Alario et al., 2004; Barry, Morrison, & Ellis, 1997; Cuetos, Ellis, & Álvarez, 1999; Ellis & Morrison, 1998; Jescheniak & Levelt, 1994; Vitkovitch & Tyrrel, 1995). Indeed, differences on one of these variables (imageability) have been argued to be the real cause of a spurious verb impairment found in several aphasic patients (Bird, Howard, & Franklin, 2000).

Thus a principal goal of the present study was to compare object and action naming using stimuli matched between the grammatical classes on a wider set of the key psycholinguistic dimensions than has hitherto been achieved. We wanted to investigate whether any grammatical class difference that might be observed would disappear once we tested naming with a sufficiently well controlled set of stimuli. We submit that our study embodied an improvement compared to previous studies in three further aspects.

Firstly, we note it has been suggested that English is a problematic language in which to compare the preservation of object/noun and action/verb knowledge because many items in the English lexicon are ambiguous in relation to their grammatical class when produced as single words (Bogka et al., 2003). This could pose a problem that applies to many of the cited studies in relation to the interpretation of observations concerning the effect of grammatical class on picture naming. This is because the noun and verb usages of the same word can be very different in terms of psycholinguistic variables such as lexical frequency, for example, “(to) laugh”, (CELEX frequency 3058 per corpus); “(a) laugh” (CELEX frequency 453 per corpus). Thus, the possible confounding of grammatical class differences with variation on key psycholinguistic variables might not have been adequately controlled in some previous studies conducted in English because matching did not address, for example, both the verb frequency and the noun frequency of a word. In addition, critically, the noun-verb ambiguity for many word forms means that some words would be related to two different semantic concepts (an object and an action) while others would be directly linked to only one concept (an object or an action). It seems to us likely that this, also, could have a potentially significant impact on naming performance. In the present article, we report an investigation of object and action naming in Spanish, a language in which grammatically uninflected forms of nouns and verbs are clearly distinguished by morphological form, for example, “pintar” (to paint), “pintura” (paint), “reír” (to laugh), “risa” (laugh).

Secondly, in previous studies researchers have employed black and white drawings in the object and action naming tasks but it has been demonstrated that object recognition and naming accuracy is significantly improved by the use of colour in target pictures (Rossion & Pourtois, 2004). Thus we presented coloured pictures so as to maximize the possible accuracy of patient naming.

Finally, we make a novel contribution through the analysis of accuracy using a technique, mixed-effects analyses, that, as we explain below, is not vulnerable to many of the problems associated with a number of commonly employed analytic approaches. Generalized linear mixed-effects modelling (Baayen, 2007) can be understood as an extension of multiple logistic regression that takes into account variance due to sampling, including, simultaneously, random variation between subjects and random variation between items. Mixed-effects modelling is warranted by the presence of correlations between responses for every participant and between participants for every item resulting from the repeated measures design we used, in common with most other investigators in this field. Moreover, mixed-effects modelling affords the critical advantage that it allowed us to address effects on naming at both the participant-level and at the item-level (Baayen, Davidson, & Battes, in press), as we shall discuss.

2. Method

2.1 Participants

Two groups, consisting of a total of 40 adults, 20 patients with a diagnosis of probable Alzheimer's disease (12 females) and 20 healthy adult control participants (13 females), participated in the study. Written informed consent was obtained from all participants or their caregivers where appropriate.

The patients were diagnosed with AD according to the criteria developed by the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) and the Alzheimer's Disease and Related Disorders Association (ADRDA), which consist of inclusion and exclusion criteria (McKhann et al., 1984; Tierney et al., 1988). All the patients participating in our study presented with cognitive impairment, as evidenced by their MiniMental State Evaluation (MMSE) scores (participants' demographic characteristics are presented in Table 1) and a clinical history of cognitive deterioration at the time of diagnosis. Visual-perceptual deficits were screened with the overlapping figures subtest of the Barcelona Battery (Peña-Casanova, 1990). Only patients who showed preserved performance in this task participated in the study. No patient had a history of psychiatric disorder or alcohol abuse. Neuroimaging tests conducted on each patient served to rule out other sources of cognitive impairment such as focal lesions or leucoariosis. Twenty healthy adults, matched in age and educational level to the experimental group (age, Kolmogorov-Smirnov $Z = 0.79$, $p > 0.10$; education, $Z = 0.63$, $p > 0.10$; 2-tailed), but differing on MMSE score ($Z = 3.16$, $p < .001$) were tested as a control group.

(Table 1, about here)

2.2 Materials

We selected 50 pictures of objects and 50 pictures of actions for use in the naming test. A list of the stimuli used is presented in the Appendix. The object pictures were taken from the coloured version (Rossion & Pourtois, 2004) of the Snodgrass and Vanderwart (1980) set. The action pictures were taken from the Druks and Masterson (2000) Object and Action naming battery, and were coloured by ourselves.

Values for the name agreement of the action pictures, the percentage of speakers who assign the target name to a given picture, were taken from those gathered in a normative study reported by Cuetos and Alija (2003) in which 50 healthy adult participants, all native Spanish speakers studying at the University of Oviedo. Name agreement data concerning the object pictures were collected by ourselves, from 55 Oviedo undergraduates, in a normative survey employing the same method as that used by Cuetos & Alija (2003). Values for the visual complexity of the action pictures were obtained using the JPEG compression method described in Bates et al. (2003), which provides an objective measure of how complex a picture is, avoiding the confounds with other variables that appear when subjective ratings are used (Forsythe, Mulhern, & Sawey, 2008). Data concerning the frequency of occurrence of picture names were taken from the Spanish Buscapalabras database (Davis & Perea, 2005) which is based on the LEXESP corpus (Sebastián-Gallés, Carreiras, Cuetos, & Martí, 2000). In our analyses, we used the log(base 10) transformed values of lexical frequencies per million. We used the estimates of the picture names' orthographic neighbourhood size (Coltheart, Davelaar, Jonasson, & Besner, 1977) calculated also by Buscapalabras. Values for the rated imageability of picture names, how easy it is to elicit the image of the concept represented by a word, of picture names (on a 7-point scale), were taken from the Valle-Arroyo (1999) database. Where imageability data were missing, we gathered values from a similar participant sample using the same methods as those reported by Valle-Arroyo (1999). We took ratings of AoA (on a 7-point scale, each point on the scale representing 2 years in the life of the participant) for some verbs from those reported by Cuetos and Alija (2003). Values for rated AoA for the remaining verbs and for the nouns were gathered by us in a survey employing the same methods and a participant sample similar to that employed by Cuetos and Alija (2003). A summary of item characteristics is reported in Table 2.

(Table 2, about here)

Action and object pictures were selected so that the pictures and the picture names were matched as far as possible. We compared actions/verbs and objects/nouns on each factor using the Kolmogorov-Smirnov test of the significance of a difference between two independent samples. We found that objects (nouns) and actions (verbs) were not significantly different on neighbourhood size, log frequency, length in phonemes, imageability, AoA, and name agreement (all tests, $p > .05$, 2-tailed). However, nouns were longer on syllable length than verbs ($Z = 1.8$, $p = .003$, 2-tailed) and action pictures were found to be of greater visual complexity than object pictures ($Z = 2.2$, $p < .001$, 2-tailed). Five objects and actions pictures were selected for use prior to the experimental phase of testing. These practice items were similar to the experimental items on the variables discussed.

2.3 Procedure

Participants were tested individually. They were instructed to name the depicted objects or actions using single word names. Action names were required in the infinitive verb form. Participants were asked to first name the set of practice stimuli to make sure they had understood the instructions. They were then asked to name the experimental target pictures. The experimenter kept a record of every response. The object and action naming tasks were presented in two different sessions as part of a wider cognitive assessment. Each naming test was the first task in a session. The order of the sessions was counterbalanced over participants.

2.4 Data analysis method

The analysis of the factors that influence patient naming is useful for the characterization of cognitive impairment in relation to the levels of processing that may have been impaired (Nickels & Howard, 1995; Shallice, 1988). However, critical item characteristics such as frequency, AoA and imageability are frequently found to be correlated in experimental item samples in psycholinguistic research, as indeed they are for the words sampled in the present study (see Table 3). This correlation is a condition that may give rise to problems including instability in the significance of predictors over different item samples (Cohen & Cohen, 1983). There are several possible approaches to this problem. We chose to render these variables orthogonal to each other through regression analyses.

(Table 3, about here)

We regressed rated item AoA on item frequency and we regressed imageability on AoA. We found that AoA was significantly predicted by log frequency (adjusted $R^2 = .17$; $F(1,98) = 21.9$, $p < .001$; $\beta = -.43$, $t = -4.7$, $p < .001$). The residuals of the regression of AoA on frequency – the difference between the observed AoA and the AoA predicted by frequency – represent that variance in item AoA that cannot be accounted for by, and is thus independent of, item frequency. We took the residuals as orthogonal AoA for use in our analyses. We found that imageability is significantly predicted by AoA for our items (adjusted $R^2 = .10$; $F(1,98) = 12.3$, $p = .001$; $\beta = -.33$, $t = -3.5$, $p = .001$). The residuals of the regression of imageability on AoA represent that variance in item imageability that is independent of AoA. We took the residuals of the regression of imageability on AoA as orthogonal imageability for use in our analyses. A check indicated that neither the correlation of frequency and orthogonal AoA nor the correlation of orthogonal AoA and orthogonal imageability was significant (see Table 3). The use of orthogonal variables supports the validity of our analyses.

We analyzed the occurrence of correct responses using the Generalized Linear Mixed-effects Models (GLMM) analytic approach (Baayen, 2007; see, also, for discussions of mixed-effects analyses, in general, Hoffman & Rovine, 2007; Quené & van den Bergh, 2004). In GLMM analyses, one evaluates models of the likelihood (actually, the logit or log odds ratio) that a correct response or an error of a certain type would be elicited by a particular item in a participant's naming. The models address raw scores rather than aggregated scores, such as the proportion of responses correct, thus avoiding the loss of information and also the serious problems associated with trying to model proportions using ordinary least squares multiple regression (Baayen, 2007). Mixed-effects modelling is advisable where all participants are tested with the same stimulus set, that is, where one has conducted a repeated-measures study. This is because responses made by the same participant will not be independent of one another (responses made by different participants to the same item will also be correlated), breaking the assumption of the non-independence of observations (Twisk, 2006), which underlies the validity of methods like multiple regression.

3. Results

Only the first response recorded in each trial was entered for analysis. We counted as correct those responses that matched the standard picture name. We note that in Spanish it is common to name some actions using a phrasal or auxiliary verb form rather than a single word, for example, the action "to jump" can be named either as /saltar/ (to jump) or as /dar saltos/ (to give jumps). A specific response category was created for this kind of responses as well as for synonymous terms. Incorrect responses were classified according to twelve mutually exclusive categories following an adapted version of the classification scheme used by Druks et al. (2006). Examples of each error type are given in Table 4.

(Table 4, about here)

Semantically related errors were classified as coordinate, superordinate, subordinate, or associative errors. A coordinate error named an object or action sharing the same category as the pictured concept, at the same level of specification. Superordinate errors named the categories to which pictured concepts belonged. Subordinate errors named an object or action sharing the same category but at a more detailed level of specification compared to the pictured concept. We note that the hierarchical organization of action concepts is not as clear as in the object concepts domain (Morris & Murphy, 1990) so the separation between sub-/superordinate and coordinate errors in the action naming task should be taken with caution. Errors semantically related to the target but belonging to a different semantic category were classed as associative errors. We categorized as visual errors those responses naming objects or actions visually similar but otherwise semantically unrelated to the target object or action. When the participant named an object or action that appeared in the picture but was different from the target concept, the error was categorized as a misinterpretation. Other than semantic or visual errors, we distinguished circumlocutions, class, formal and unrelated errors as well as perseverations and null responses. Circumlocutions were multi-word descriptions used to convey the meaning of the target picture that were not phrasal verb forms. Errors were categorized as class errors if the errors named a concept semantically related to the target concept but belonging to a different grammatical class. We classified as formal errors those responses sharing more than 50% of their phonemes with the target word. Perseverations consisted of repetitions of a previous response. Unrelated errors did not present an identifiable relation between error and target under any of the already mentioned categories. Null responses were counted where participants refused to make a response or did not make an intelligible response. The frequencies of different response types are reported in Table 5.

(Table 5, about here)

The patients made more errors of all types compared to the controls. Both groups tended to produce more errors overall to actions than to objects though the grammatical class difference was small for the controls. Patients and controls made many coordinate, superordinate or visual errors to actions and objects. However, whereas patients made several null responses, misinterpretations, circumlocutions and unrelated errors, these error types were substantially less frequent in control performance. The occurrence of misinterpretations or class errors was largely confined to patients' responses to action pictures. Circumlocutions, visual or unrelated errors were made more frequently to actions than to objects by patients as well as controls. Null responses and coordinate errors were made more frequently to objects than to actions by both groups.

We analyzed the occurrence of correct responses using the Generalized Linear Mixed-effects Models (GLMM) analytic approach by means of the lme4 package (Bates, 2005) in R, an open source language and environment for statistical computing (R Development Core Team, 2005). Even though it has been stated, above, that phrasal verb forms and synonyms are commonly used in standard speech, only exact matches to the target words were examined in the present analysis because item characteristics such as frequency pertain to the expected target picture name. However, we note that we conducted parallel analyses in which phrasal forms or synonyms were also counted as correct and that in those analyses we found patterns of significant or non-significant effects similar to the ones we report below.

We looked, firstly, at the item-level and participant-level factors, as well as the cross-level interactions, that would predict accuracy of naming by all participants to all items. We evaluated a model including the following factors: 1. at the participant-level, participant type (patient or control), as well as participant age and education; 2. at the item-level, grammatical class, orthographic neighbourhood size, word length in phonemes or in syllables, lexical frequency, orthogonal lexical AoA, orthogonal imageability, picture visual complexity, and picture name agreement. We centred continuous numeric variables on their means to render them more easily interpretable (Cohen & Cohen, 1983) since such variables as, for example, age, do not have natural zeroes. We did not centre orthogonal AoA or imageability because these variables already vary about zero. The model also included terms accounting for cross-level interaction effects between the item-level effects and participant type as a categorical variable (participants were classed as patients or controls). The results of the analyses are presented in Table 6. It should be noted that positive coefficients indicate that an increase in the corresponding variable is associated with an increase in the likelihood that a response would be correct whereas negative coefficients indicate that an increase in the variable is associated with a decrease in the likelihood that a response would be correct.

(Table 6, about here)

The following observations can be made. Firstly, patients were significantly less likely than controls to name pictures accurately. Secondly, pictures with higher name agreement were more likely to be named accurately. Thirdly, an interaction between participant group and picture visual complexity affected accuracy: controls were more likely to name pictures correctly, especially if those pictures were visually more complex. We note that the model fit statistics, C and Dxy, indicated excellent fits between the predicted probabilities of correct or incorrect naming and the observed response for every model.

We were especially interested in looking at what factors predicted the likelihood of accuracy for each participant group, considered separately. For this new set of analyses, we introduced all the previously used variables but now added MMSE scores so that we could evaluate whether this measure of cognitive deterioration could account for the participants' performance. The results of the separate group analyses can be seen in Table 7.

(Table 7, about here)

We found that control group naming was not significantly affected by any factor, probably due to the fact that control group naming accuracy approached ceiling; the controls were much more accurate than the patients. Contrastingly, the likelihood that a patient's naming would be correct was significantly affected by frequency, AoA and name agreement. None of the other factors, including grammatical class and MMSE score, significantly affected patients' performance. Again, C and Dxy indices for this model indicated an excellent fit between predicted probability and observed accuracy. It is noteworthy that the group x visual complexity interaction effect reported for the overall analysis did not entail effects of visual complexity for patients only. We think that this is likely due to the relatively small size of the mentioned effect, which diminished magnitude would be less likely to be discriminable in the smaller data-set available for the separate group analyses. It is also noteworthy that the effect of name agreement was discerned to influence patient naming only, though a main effect of this variable had been indicated in the overall analyses, and though no significant interaction had been indicated between group and name agreement. We would point out that the effect of name agreement on controls' naming accuracy approaches significance at the .05 level, and submit that it is likely that a ceiling effect should be held to account for the lack of significance in this instance. The appearance of an AoA effect influencing patient but not control naming is intriguing because no AoA main or interaction effect was indicated in the overall analysis. We note that it would seem sensible to address the latter with some caution.

4. Discussion

Several studies have explored the relative preservation of AD patients' ability to name objects and actions but the evidence has presented an inconsistent pattern. The purpose of the present study was to clarify the relative preservation of action and object naming by using stimuli matched on a more extensive set of factors than previously achieved, including lexical age of acquisition, imageability, frequency, neighbourhood size, length, and picture name agreement, in a language, Spanish, in which ambiguity concerning the grammatical class of picture names is eliminated. Our main finding was that our participants' naming accuracy was significantly predicted overall by effects of participant group (patients produced less correct responses), name agreement (accurate naming was more likely to pictures with higher name agreement), and the effect of an interaction between participant group and picture visual complexity. Further analyses conducted to probe the factors influencing naming for each group considered separately showed that control naming accuracy was not significantly predicted by any factor available to our analysis while patient accuracy was predicted by frequency, AoA and name agreement. In sum, our findings indicate no evidence for the effect of grammatical class on picture naming accuracy while other effects are clearly more important to our account, principally, the effects of the consistency with which pictures are normally named (the effect of name agreement) and the experience individuals had previously gained in using picture names (picture name frequency or AoA).

We observed a pattern of error production is in line with the results of the study by Druks et al. (2006). In the two studies, coordinate errors were more often produced in response to object naming, whereas misinterpretations and circumlocutions were made more often on action naming. Interestingly, in the Druks et al. (2006) study, semantically related errors counted as a group - including coordinate and superordinate errors - were the most frequent error type, just as we found. These kind of errors would arise from the impact of the lesions caused by dementia on the network representing semantic knowledge, where such impact would include the degradation of semantic representations (Garrard, Lambon Ralph, Patterson, Pratt, & Hodges, 2005; Hodges et al., 1992) but might also include diminution in the activation of the semantic system which gives rise to difficulties in the mapping between semantics and the lexicon (Cuetos, González-Nosti et al., 2005).

As we have noted, previous studies addressing the issue of the effect of grammatical class on AD patient naming have found various patterns, either a significant advantage in action naming (Bowles et al., 1987; Fung et al., 2001; Robinson et al., 1999; Williamson et al., 1998) or a significant advantage in object naming (Druks et al., 2006; Kim & Thomson, 2004; Masterson et al., 2007; Robinson et al., 1996; White-Devine et al., 1996). We would argue that our results are in line with the null effect of grammatical class reported by Cappa et al. (1998) in Italian. We submit that at least one source of the inconsistency among previous observations is likely to have arisen from uncontrolled variation in the characteristics of the items used in different studies. Moreover, we submit that previous work done in English may have observed inconsistent object-action naming differences due to the confounding of the psycholinguistic characteristics of the verb and noun forms of the same word. These inconsistencies could have maximized the problem of the lack of control over word characteristics.

In our study, the name agreement of the pictures as well as the frequency and AoA of the names of the pictures have been found to be significant predictors of the accuracy of the patient group.To explain the effect of name agreement, following Vitkovitch and Tyrrell (1995), we assume that when the picture of an object (or action) is presented, the different correct names for it become available at the name retrieval stage. One influential model of lexical selection for speech production assumes that lexical selection occurs at the resolution of a process of competition between different candidates activated by a picture stimulus (Levelt, Roelofs, & Meyer, 1999; Roelofs, 1992). The greater the number of possible labels that exist for a single concept, the more difficult it is for the system to select the appropriate candidate. In the case of healthy participants, this difficulty yields longer reaction times (Vitkovitch & Tyrrel, 1995). We suggest that for AD patients an impairment of the lexical semantic system would make it sufficiently difficult for the appropriate name to be retrieved that, for pictures with lower name agreement and, as we will discuss, lower frequency or later-acquired names, lexical competition would result more often in selection of the wrong name. Such semantic impairment is consistent with the predominance of semantically related errors among the errors produced by patients in the present study.

It has been argued that the lesions resulting from dementing illness (Garrard et al., 2005; Hodges et al., 1992) tend to result in the degradation of semantic knowledge so that concept representations are rendered less item-specific and more generic. Persuasive evidence that there is a link between the preservation of semantic knowledge and the extent of naming success is provided in the observation that more semantic information is evidenced by AD patients, in probed tests of semantic attributes, corresponding to concepts that they can name compared to concepts that they cannot name (Garrard et al., 2005). If degradation in the specificity of representations is indeed the nature of the semantic deficit in AD patients, then the activation reaching lexical candidates from the semantic system as a result of picture presentation would afford less precise information and thus would make it more difficult to select the correct candidate, particularly where name agreement is lower. Thus the name agreement effect is precisely what one would expect to find.

Regarding frequency and AoA, these variables have been shown to have an effect on the picture naming reaction times of young (Bates, Burani, D'Amico, & Barca, 2001) and on the naming accuracy of older healthy adult participants (Hodgson & Ellis, 1998) as well as on the naming accuracy of aphasic (Cuetos, Aguado, Izura, & Ellis, 2002; Cuetos, Monsalve, & Pérez, 2005; Hirsh & Funnell, 1995; Nickels & Howard, 1995) and dementia patients (Silveri, Cappa, Mariotti, & Puopolo, 2002). One theory of why there might generally be frequency and AoA effects - the effects of experience in using picture names - can be derived by beginning with the idea that earlier-acquired picture names are better competitors in the process of lexical selection (Belke, Brysbaert, Meyer, & Ghyselinck, 2005). This greater competitiveness arises naturally in the theory of semantic knowledge growth reported by Steyvers and Tenenbaum (2005).

In the Steyvers and Tenenbaum (2005) account, growth in semantic knowledge through the life span depends upon a process in which connections are introduced primarily between new and existing semantic representations. One consequence of this form of growth is that earlier-acquired representations should possess more connections than later-acquired representations. It would seem likely that, because of this greater connectedness, in the picture naming task stimuli would evoke activation of earlier-acquired concepts more quickly and to a greater extent than would be the case for later-acquired concepts. More quickly or more strongly activated concepts are more likely to activate a lexical name that would be selected for speech output in most current views of speech production (e.g. Roelofs, 1992). This should lead to faster naming latencies in healthy adults but would also predict a greater likelihood of accuracy in patient naming. In fact, this mechanism has been shown to be responsible for the differences in the patterns of deterioration of different semantic categories of objects in AD patients (Aronoff et al., 2006; Gonnerman, Andersen, Devlin, Kempler, & Seidenberg, 1997) arguing that highly intercorrelated concepts resist damage more efficiently because information that becomes unavailable for one concept can be reached indirectly through related concepts.

A similar account would explain the fact that patients had better scores in response to pictures with high frequency compared to low frequency names. This effect has also been found in previous studies (Williamson et al., 1998). We argue that, like the AoA effect, the frequency effect reflects the influence of frequency on lexical selection. In the Steyvers and Tenenbaum (2005) model, the lexical frequency of a word is assumed to reflect its utility in the growth of semantic knowledge, that is, the probability that its representation would be the target of new connections. As a result, high frequency nodes acquire more connections to new nodes at a higher rate. Again, as words with greater numbers of connections are activated more quickly, the lexical entries of high frequency words would be more likely to be selected than those of low frequency words. Likewise, the relation between interconnectedness and the probability of concept preservation would also apply as we believe it does in explaining the AoA effect. In sum, the impairment of the semantic system associated with AD should reveal AoA and frequency effects on naming and this is what we observed.

In conclusion, in the present study, the influence of frequency, AoA and name agreement on the naming performance of a group of Spanish AD patients was identified using the state-of-the-art mixed-effects analysis approach. The effect of these variables, taken with the observed error pattern, is consistent with an account in which the lexical-semantic impairment caused by the damage associated with AD affects different items to different extents. That item by item variation is predictable in terms of variables like name agreement, which modulates the ease of lexical selection for production, and frequency and AoA, which reflect the way in which semantic knowledge is structured. However, the grammatical class to which the names of the pictures belonged did not predict the performance of our participants, suggesting that the patients' lexical-semantic impairment affected nouns and verbs to a similar extent.

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Appendix. List of the stimuli used.

Objects		Actions	
acordeón	(accordion)	abrir	(to open)
ardilla	(squirrel)	acariciar	(to caress)
avión	(plane)	atar	(to tie)
bicicleta	(bicycle)	bailar	(to dance)
cabra	(goat)	beber	(to drink)
cadena	(chain)	besar	(to kiss)
cajón	(drawer)	botar	(to bounce)
calabaza	(pumpkin)	caminar	(to walk)
camión	(truck)	cantar	(to sing)
camisa	(shirt)	cavar	(to dig)
candado	(padlock)	cocinar	(to cook)
caracol	(snail)	comer	(to eat)
cebolla	(onion)	correr	(to run)
cerdo	(pig)	cortar	(to cut)
cereza	(cherry)	coser	(to sew)
chaleco	(waistcoat)	cruzar	(to cross)
corbata	(tie)	dibujar	(to draw)
falda	(skirt)	doblar	(to bend)
flauta	(flute)	dormir	(to sleep)
fresa	(strawberry)	empujar	(to push)
gato	(cat)	encender	(to turn on)
guitarra	(guitar)	escribir	(to write)
hacha	(axe)	gatear	(to crawl)
helicóptero	(helicopter)	jugar	(to play)
león	(lion)	ladrar	(to bark)
limón	(lemon)	lamer	(to lick)
manzana	(apple)	lavar	(to wash)
martillo	(hammer)	leer	(to read)
mecedora	(rocking chair)	llorar	(to cry)
moto	(motorcycle)	llover	(to rain)
naranja	(orange)	morder	(to bite)
nariz	(nose)	nadar	(to swim)
navaja	(razor)	nevar	(to snow)
oreja	(ear)	patinar	(to skate)
oso	(bear)	pedir	(to beg)
pantalón	(trousers)	pelar	(to peal)
piano	(piano)	pescar	(to fish)
pierna	(leg)	pintar	(to paint)
piña	(pineapple)	plantar	(to plant)
rodilla	(knee)	regar	(to water)
silbato	(whistle)	reír	(to laugh)
silla	(chair)	rezar	(to pray)
sofá	(sofa)	saltar	(to jump)
tambor	(drum)	saludar	(to wave to)
tigre	(tiger)	sangrar	(to bleed)
tijeras	(scissors)	sonreír	(to smile)
tren	(train)	soñar	(to dream)
vestido	(dress)	soplar	(to blow)
violín	(violin)	tejer	(to knit)
zanahoria	(carrot)	volar	(to fly)

Table 1. Demographic details of participants

		controls	AD
participants		20	20
age (years)	Mean (S.D.)	78.2 (8.5)	82.5 (8.7)
	Minimum	66	70
	Maximum	93	99
education (years)	Mean (S.D.)	7.9 (3.3)	7.0 (2.9)
	Minimum	4	4
	Maximum	12	12
MMSE	Mean (S.D.)	29.3 (0.9)	16.6 (3.8)
	Minimum	27	9
	Maximum	30	22

Table 2. A summary of item characteristics

		objects (nouns)	actions (verbs)	class difference?
number of items		50	50	Kolmogorov-Smirnov (2-tailed test)
name agreement	mean (S.D.)	96.77 (4.25)	95.08 (6.18)	Z = 1.3, p = 0.07
visual complexity	mean (S.D.)	20.04 (5.76)	30.56 (9.34)	Z = 3.0, p < .001
neighbourhood size	mean (S.D.)	2.86 (4.77)	2.04 (2.47)	Z = 0.6, p > 0.10
log10frequency	mean (S.D.)	1.00 (0.47)	0.94 (0.59)	Z = 0.7, p > 0.10
word length (phonemes)	mean (S.D.)	5.90 (1.50)	5.72 (1.07)	Z = 0.6, p > 0.10
word length (syllables)	mean (S.D.)	2.68 (.77)	2.22 (.47)	Z = 1.8, p = 0.003
imageability	mean (S.D.)	6.28 (.41)	6.06 (.57)	Z = 1.2, p > 0.10
AoA	mean (S.D.)	2.48 (.59)	2.59 (.59)	Z = 1.0, p > 0.10

Table 3. Pair-wise (Spearman's rank) correlations between predictors

Spearman's rho	For all bivariate comparisons, N = 100.									
		VC	N	phonemes	syllables	imageability	AoA	NA	oAoA	oImg
log10(frequency)	Coefficient	-0.040	0.075	**-0.257**	-0.165	**0.264**	**-0.463**	0.091	-0.071	0.055
	p (2-tailed)	0.691	0.457	**0.010**	0.101	**0.008**	**< 0.001**	0.367	0.485	0.587
visual complexity (VC)	Coefficient		0.004	-0.143	**-0.283**	-0.014	0.061	-0.064	0.030	-0.009
	p (2-tailed)		0.965	0.156	**0.004**	0.888	0.546	0.525	0.767	0.926
neighbourhood size (N)	Coefficient			**-0.628**	**-0.463**	-0.022	-0.027	-0.088	-0.017	-0.042
	p (2-tailed)			**< 0.001**	**< 0.001**	0.824	0.789	0.385	0.870	0.681
name length (phonemes)	Coefficient				**0.759**	-0.105	0.191	0.001	0.123	-0.019
	p (2-tailed)				**< 0.001**	0.300	0.057	0.995	0.222	0.854
name length (syllables)	Coefficient					0.013	0.175	-0.003	0.124	0.105
	p (2-tailed)					0.896	0.081	0.976	0.220	0.297
imageability	Coefficient						**-0.403**	0.080	**-0.316**	**0.876**
	p (2-tailed)						**< 0.001**	0.430	**0.001**	**< 0.001**
AoA	Coefficient							0.029	**0.901**	0.052
	p (2-tailed)							0.772	**< 0.001**	0.607
name agreement (NA)	Coefficient								0.080	0.083
	p (2-tailed)								0.429	0.409
orthogonal AoA (oAoA)	Coefficient									0.096
	p (2-tailed)									0.341

Table 4. Examples of the error categories

	Objects			Actions		
	Picture		Error	Picture		Error
Coordinate errors	león (lion)	→	perro (dog)	andar (to walk)	→	correr (to run)
Superordinate errors	calabaza (pumpkin)	→	fruta (fruta)	cavar (to dig)	→	trabajar (to work)
Subordinate errors	tren (train)	→	AVE (high-speed train)	leer (to read)	→	estudiar (to study)
Associative errors	guitarra (guitar)	→	música (music)	sangrar (to bleed)	→	herir (to hurt)
Circumlocutions	candado (padlock)	→	para cerrar puertas (to lock doors)	pelar (to peal)	→	quitar la piel (to remove the skin)
Visual errors	naranja (orange)	→	luna (moon)	cantar (to sing)	→	llorar (to cry)
Misinterpretation	camisa (shirt)	→	botones (buttons)	acariciar (to stroke (a cat))	→	sentarse con un gato (to sit down with a cat)
Class-crossing errors	-	→	-	llover (to rain)	→	lluvia (rain)
Formal errors	ardilla (squirrel)	→	arcilla (clay)	-		-
Unrelated errors	acordeón (accordion)	→	cama (bed)	escribir (to write)	→	doblar (to fold)

Table 5. Summary of response (correct and error) type frequencies

	controls		AD	
grammatical class	objects	actions	objects	actions
response type	total frequency			
accuracy (exact matches only)	898	838	588	493
accuracy (synonyms only)	8	32	3	14
auxiliary form (aux)	0	23	0	21
errors	94	107	409	472
error types				
null responses	9	2	86	48
coordinate errors	63	44	195	141
superordinate errors	6	19	35	24
subordinate errors	3	1	2	1
associate errors	0	5	5	0
misinterpretations	0	7	1	84
circumlocutions	3	5	19	33
visual errors	7	18	50	67
formal errors	0	0	3	0
perseverations	0	0	2	3
unrelated errors	3	4	11	33
class-crossing errors	0	2	0	38
total number of responses	1000	1000	1000	1000

Table 6. Summary of mixed-effects model of naming accuracy over all participants

	Parameter	estimate		SE
Fixed effects				
	intercept	2,25	***	0,30
	participant group	-2,01	***	0,34
centred	age	-0,01		0,02
centred	education	-0,01		0,05
	grammatical class	-0,54		0,36
centred	neighbourhood	0,02		0,04
centred	syllables	-0,06		0,34
centred	phonemes	-0,11		0,19
centred	log10 frequency	0,31		0,26
	orthogonal AoA	-0,29		0,24
	orthogonal imageability	0,54	~	0,28
centred	visual complexity	-0,02		0,02
centred	name agreement	0,06	**	0,02
centred	group x class	0,48	~	0,29
centred	group x centred neighbourhood	0,01		0,04
centred	group x centred syllables	0,06		0,28
centred	group x centred phonemes	0,14		0,16
centred	group x centred log frequency	0,34		0,22
centred	group x orth. AoA	-0,07		0,20
centred	group x orth. Imageability	-0,18		0,23
centred	group x centred visual complexity	-0,05	**	0,02
centred	group x centred name agreement	0,03		0,02
Random effects (variance components)				
	item (intercept)	0,77		
	participant (intercept)	0,73		
Fit statistics				
	C (Concordance)	0,85		
	Dxy	0,70		
	-2 Log Likelihood	-38043		

*** if p < .001, ** if p < .01, * if p < .05, ~ if p < .10

Table 7. Summary of mixed effects models of naming accuracy in each group

	Parameter	controls			AD		
		estimate		SE	estimate		SE
Fixed effects							
	intercept	4.27	**	1.57	0.78		0.48
centred	MMSE	-0.21		0.25	0.06		0.06
centred	age	< -0.01		0.03	-0.04		0.03
centred	education	0.07		0.06	-0.10		0.07
	grammatical class	-0.54		0.46	-0.15		0.42
centred	neighbourhood	0.04		0.06	0.04		0.05
centred	syllables	-0.20		0.46	0.02		0.44
centred	phonemes	0.02		0.26	0.06		0.23
centred	log10 frequency	0.47		0.34	0.94	**	0.30
	orthogonal AoA	-0.33		0.33	-0.58	*	0.29
	orthogonal imageability	0.67	~	0.36	0.44		0.34
centred	visual complexity	0.02		0.02	-0.01		0.02
centred	name agreement	0.06	~	0.03	0.07	*	0.03
Random effects (variance components)							
	item (intercept)	1.80			1.86		
	participant (intercept)	0.48			0.70		
Fit statistics							
	C (Concordance)	0.88			0.87		
	Dxy	0.77			0.74		
	-2 Log Likelihood	-646.30			-1065.00		

*** if p < .001, ** if p < .01, * if p < .05, ~ if p < .10