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Lexical relation processes and reaction times in Spanish-speaking older adults

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Abstract: This study analyzes the routes of lexical relations in Spanish-speaking older adults, using a free word association task that focuses on differences in reaction times according to the type of lexical relation and the influence of the semantic category of stimulus words. Older adults performed a free word association task by responding orally with one word to a one-word stimulus classified according to a semantic coherence criterion. Response words were classified by type of lexical relation: paradigmatic or syntagmatic. Reaction time was measured as the time elapsed before producing a response word. Older adults produced more paradigmatic than syntagmatic responses, and paradigmatic responses showed longer reaction times than syntagmatic responses. Mixed-effects analysis revealed that the semantic categories of stimuli influence the type of lexical relation, and that reaction times are influenced by these semantic categories and by the type of lexical relation. Reaction times and lexical relation types were not influenced by either age or years

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of education. We identify differentiated grammatical and semantic processing of the mental lexicon.

Keywords: lexical relations; reaction time; semantics; free word association task

1 Introduction

Vocabulary, or the mental lexicon, is organized in semantic memory, which stores knowledge about words and other verbal symbols, including meanings and referents as well as the relationships between them (Tulving 1972). We are interested in studying the mental lexicon in older adults whose vocabulary has reached its peak (Hartshorne and Germine 2015) to know how it is organized.

Clark (1970) first studied semantic memory processes through the analysis of lexical relations between two words. The theoretical model of the lexical network, known as the spreading activation model, assumes that mental vocabulary is organized by its semantic characteristics, where each word is regarded as a node, and proximity between nodes determines the degree of association as well as the propagation of activation of neighboring nodes (Collins and Loftus 1975; Dubossarsky et al. 2017). Words have a semantic organization within the mental lexicon, but grammatical relations between words also influence the organization of the lexical network (Norvig 1989). This traditional lexical network model assumes words to be an exact mapping of meaning; however, other models consider words as grammatical or sensory cues that help construct meaning (Lupyan and Lewis 2019). For example, Barsalou et al. (2003) propose a modal approach in which cognitive-level representations that support memory and language are provided by re-enactments/simulation processes that integrate information across several modalities of sensory representation linked to specific contexts. We argue that the organization of the mental lexicon is an outgrowth of semantic and grammatical contexts based on embodied sensory experiences with each word and its meaning (Barsalou et al. 2018). From this theoretical perspective, sensory experience is constrained by our bodily interactions with the environment and the objects within it, which enhance the grounding of word meaning (Barsalou et al. 2003; Fernandino et al. 2016).

Lexical relation tasks are traditionally used to model the mental lexicon in word networks. This approach assumes that when two words are connected in the mental lexicon, they are likely to be paired in a word association task (De Deyne et al. 2019; Dubossarsky et al. 2017). This topographical semantic representation of the mental lexicon assumes that in a word association task, the propagation of activation primarily follows semantic rather than grammatical criteria, despite words having both semantic and grammatical features (Clark 1970; Collins and Loftus 1975; Collins and Quillian 1969; Lupyan and Lewis 2019).

Callejas et al. (2003) demonstrated that word association tasks in Spanish show a differentiated pattern of associated responses based on the semantic category of the cue word. These researchers generated a database of intra-category associative norms to study intra-categorial associative strength and subjective familiarity. Based on a criterion of semantic coherence, they grouped a set of 612 stimulus words into six different categories: animals; food and drink; atmospheric agents and geographical features; buildings and furniture; clothing, footwear, and accessories; and parts of the human body. Their findings indicated that the categories 'parts of the human body' and 'animals' showed greater internal consistency than the others; that is, these categories had a lower number of different associated words, a greater associative strength in the first associated word (the answer given by a greater number of participants), and a lower percentage of idiosyncratic responses. The category 'clothing, footwear, and accessories' presented lower internal consistency.

We interpret the findings regarding semantic association strength and the need for a dual path (Callejas et al. 2003; De Deyne et al. 2019; Dubossarsky et al. 2017) as evidence supporting the existence of at least two spreading activation pathways during language processing – one grammatical and one semantic. Furthermore, we suggest that the activation must flow through both paths for word associations to occur. The present study proposes a differentiated grammatical and semantic organization in the mental lexicon of older adults based on language contexts, with a consequent dual path spreading activation. We tested this proposal with a free word association task to analyze the types of lexical relations and the reaction times of older adults.

Free word association tasks enable the analysis of spontaneous lexical production, providing insights into lexical relations in both adults (De Deyne et al. 2019; Fitzpatrick 2007; Goldfarb and Halpern 1984; Hirsh and Tree 2001) and children (Barrón-Martínez and Arias-Trejo 2014; Mann et al. 2016; Namei 2004). Such tasks provide a non-invasive way to understand the development of lexical networking, the type of association between a stimulus word and its response, and information regarding semantic memory. Lexical relations can be studied by their grammatical closeness: the relation is paradigmatic when two words have the same grammatical class (e.g., noun-noun), and syntagmatic when they are from different grammatical classes (e.g., noun-verb) (Clark 1970; Ervin 1961; Minto-García et al. 2020). Lexical relations support features of the underlying mechanisms of language processing (Clark 1970; Fitzpatrick 2007; Minto-García et al. 2020) such as spreading activation routes of word networks in the mental lexicon.

Comparisons between younger and older adults have been carried out in previous studies (e.g., Arias-Trejo et al. 2022; Hirsh and Tree 2001; Tresselt and Mayzner 1964; Zortea et al. 2014). These studies involve languages with different degrees of lexicality, which is relevant because highly lexicalized languages, like English, are believed to have more ambiguous morphotactic stream activation than languages, like Spanish, that have richer morphology (Blanco-Elorrieta and Caramazza 2021). The lexicality of a language, in turn, creates differences in the way participants process lexical and grammatical information from words during a free word association task. With respect to the organization of word associations in semantic memory, studies with English speakers have found few changes with age in the organization of word associations in semantic memory (Burke and Peters 1986; James and MacKay 2007; Tresselt and Mayzner 1964). Furthermore, age appears to have no impact on lexical relations in older adults during word association tasks. Previous studies have reported a 60 % coincidence in the most frequent responses between younger and older adults (Burke and Peters 1986; Hirsh and Tree 2001). Recently, Arias-Trejo et al. (2022) found that in 38.46 % of the stimuli, both older and young adults produced the same most frequent associate, and the strength of association for the first associate was comparable in both groups.

Conversely, several studies have identified differences in semantic memory between younger and older adults. Researchers have found an increase in the degree centrality of the word network and the interconnectivity among nodes for older participants (Zortea et al. 2014), which can enhance the activation of the network (Borovsky and Peters 2019). Moreover, some studies have reported significant differences in the variability of the responses – that is, the number of different responses for a given stimulus word – between age groups (Hirsh and Tree 2001; Tresselt and Mayzner 1964). Studies in English and Dutch have reported greater variability in word associations among older adults compared to younger ones – a result of the older adults' broader vocabulary (e.g., Burke and Peters 1986; Dubossarsky et al. 2017; Hartshorne and Germine 2015; Lovelace and Cooley 1982). Likewise, in Mexican older adults, it was observed that the number of different responses for each stimulus word was significantly larger than that of young adults (Arias-Trejo et al. 2022).

Vocabulary reaches its peak during old age (Hartshorne and Germine 2015). Burke and Peters (1986), who focused on English speakers, performed a comparative analysis between young adults (aged 18–33) and older adults (aged 62–87) of word relationships generated in a free association task. Their analysis was carried out using association norms for 113 words, with nouns, verbs, adjectives, and adverbs as stimulus words. They found that with their larger vocabularies, older adults tended to generate more unique responses, confirming that vocabulary was a good predictor of variability in word association. The differences identified between young and older adults have thus not been attributed mainly to age, but to the breadth of vocabulary (Burke and Peters 1986) and the accumulation of experience with their language (Ramscar et al. 2017). Moreover, although the type of language exposure (written or spoken) yields a different amount of vocabulary a person is exposed to and can consequently learn, both age and educational level also have an impact on the number of words known, namely, on vocabulary size. That is, the more a person is exposed to language, the more words they learn with a steady increase observed by the age of 70 (Brysbaert et al. 2016). In this context, the present study is interested in the mental lexicon of older adults over 60 years old, whose lexical network has complex links between words (Arias-Trejo et al. 2022), which, from our point of view, is a consequence of a rich vocabulary.

In comparative analyses of types of lexical relations, Burke and Peters (1986) and Lovelace and Cooley (1982) found that both older and younger adults produced more paradigmatic than syntagmatic responses in word association tasks, although a study of German speakers reported a decrease in paradigmatic responses with age (Riegel and Riegel 1964). Studies with Mexican older adults with typical aging (without a diagnosis of neurodegenerative disease) also observed a preference for paradigmatic responses (Flores-Coronado et al. 2019; Minto-García et al. 2020). Other studies have found that types of lexical relations are associated with the type of stimulus word, specifically its grammatical class (see, for example, Goldfarb and Halpern 1984). In the present study, we consider the role of the stimulus word and focus on the propagation of activation during a word association task, differentiating paradigmatic from syntagmatic relations (using a grammatical classification) according to the semantic category of stimulus words to explore grammatical and semantic propagation activation in older adults.

Older adults present complications in prospective and episodic memory (Arango-Lasprilla et al. 2003), as well as a decrease in processing speed, which in turn mediates language processing (Verhaeghen and Salthouse 1997). Research characterizes processing speed in older adults; however, it does so without considering changes in what is processed across the lifespan. For instance, in a lexical decision task, older adults are more accurate than younger adults despite taking longer to respond (Baayen et al. 2017; Caplan and Waters 2005; Ramscar et al. 2013). Furthermore, Caplan and Waters (2005) have shown that older adults require more time to process language – to understand complex sentences – than younger adults; however, despite their increase in reaction time, semantic recovery does not decline. A few studies have shown that language is the cognitive process least affected by age, especially concerning vocabulary (Brysbaert et al. 2016; De Deyne et al. 2019; Zortea et al. 2014). In this regard, older adults are believed to preserve their vocabulary or increase it with age, which reflects their lexical experiences (Brysbaert et al. 2016; Harada et al. 2013; Hartshorne and Germine 2015). Cumulative linguistic experience has an impact on the knowledge of the lexicon (Ramscar et al. 2017). Changes in cognitive performance in older adults reflect the effects of increased knowledge rather than cognitive decline (Ramscar et al. 2014). The time it takes to generate a response to a stimulus was studied through a word association task by Arias-Trejo et al. (2022). This study identified a negative correlation between word association strength and response time; that is, words that are highly related to their stimulus are produced faster. This finding reflects the organization proposed in the spreading activation model in which the close distance between words (reflected in faster stimulus response latencies) implies a high degree of associative strength (Collins and Loftus 1975). Analyzing the reaction time of older adults in a free word association task will help us understand propagation activation within the lexical network, shedding light on how processes work within specific semantic and grammatical clusters, and it can verify the existence of differentiated semantic and grammatical processes.

Seeing as previous studies comparing younger and older adults have found differences primarily due to vocabulary breadth, our focus here lies on studying the underlying processes of language organization in the vast lexicon of older adults. Given the increase in life expectancy that has allowed a growth in the elderly population (World Health Organization 2021), we believe that it is important to study the semantic memory and language of older adults to gain a better understanding of these mechanisms that impact daily life. We also hope that our findings will provide a baseline for future comparisons with people with neurodegenerative diseases (which commonly occur with aging).

Unlike Minto-García et al. (2020), who focused their analysis on the type of lexical relations, our study aims to examine the propagation of activation routes of lexical relations in Mexican Spanish-speaking older adults. Moreover, a free word association task was used to observe the mental lexicon's processes when it is built upon a wide vocabulary. Specifically, it analyzes whether there are differences in reaction times according to the type of lexical relation (paradigmatic or syntagmatic), and whether the semantic characteristics of the stimulus words influence the type of lexical relations generated by older adults.

2 Methods

2.1 Participants

Participants were 60 older adults aged 60–80 years (M = 68.78, SD = 7.46), men (n = 20) and women (n = 40); all were native speakers of Spanish from the central region of Mexico, with a mean education of 10.56 years (SD = 4.79, range: 3–19). They were recruited from public and private institutions that provide care for the older population. All participants provided written informed consent and completed a sociodemographic questionnaire used to determine eligibility based on inclusion criteria for sex, age, and years of education. The questionnaire also collected information regarding the use of any medication that could affect task performance. Information was also requested concerning previous medical diagnoses of any condition that could affect their cognitive state (e.g., Alzheimer's disease or stroke). Older adults with any self-reported neurological disorder were excluded from the study. This study was performed in line with the principles of the Declaration of Helsinki.

2.2 Stimuli

Stimuli were 95 high-frequency – according to the frequency of use reported by the Wordbank database on words used by Spanish speakers (Frank et al. 2016); *M* = 0.67, SD = 0.17 – nouns of early acquisition taken from the Spanish MacArthur-Bates Communicative Development Inventories (CDI) (Jackson-Maldonado et al. 2003). The stimuli were classified according to a semantic coherence criterion (Callejas et al. 2003) as animals, food, places, inanimate familiar objects, or tools. These semantic categories of the stimulus include others that coincide in semantic features. For example, although *almohada* 'pillow' and *jabón* 'soap' could be included in different semantic categories (bedroom objects and bathroom objects), they can both be grouped in the semantic category of inanimate familiar objects. Semantic coherence criteria exploit embodied experiences: people have different embodied experiences with tools than with places, for example, they actively manipulate tools, but not places, with their hands (Connell and Lynott 2009; Lynott et al. 2020). We expect these embodied differences to affect the type of responses given. The semantic categories were defined as follows:

a. Animals: any type of animal (domestic or wild) regardless of habitat or physical similarities (e.g., *araña* 'spider').
b. Food: solid or liquid food (e.g., *cacahuate* 'peanut').
c. Places: physically delimited locations or objects that are fixed in place or occupy a certain space. All words in this category allow the use of the Spanish locative preposition *en* 'in/on' (e.g., *alberca* 'swimming pool').
d. Inanimate familiar objects: common objects that are part of people's daily or meaningful experience (e.g., *almohada* 'pillow') but have no instrumental function.
e. Tools: common objects with an instrumental function (e.g., *tijeras* 'scissors').

Since the categories 'inanimate familiar objects' and 'tools' might have overlapping boundaries, the feature of functionality (as an extension of the human hand, or as a tool to facilitate an affordance-based task that meets a human need) was considered, primarily to classify a stimulus in the tools category.

Although the nouns included in the CDI would have allowed us to integrate groups of words from other semantic categories (e.g., clothing), we only selected nouns that enabled us to form sets with approximately the same number of words for each semantic category according to embodied experiences. The Appendix shows the selected stimuli, their semantic coherence classification, and their frequency of use according to the Wordbank database (Frank et al. 2016). Three stimuli were used as practice (*tazón* 'bowl', *bocina* 'speaker', and *cucaracha* 'cockroach') to ensure that participants understood the task.

2.3 Free word association task

The free word association task was completed using the computer program SS_Palabras 2.0, developed at the National Autonomous University of Mexico (UNAM). Participants performed the task individually. The researcher explained the procedure, and immediately after, the participants listened to a series of stimulus words one by one. Participants responded orally to each word with the first word that came to mind; they were given 60 s to respond to each stimulus word. If they did not respond within the first 30-second mark, the protocol established that the researcher should repeat the stimulus. None of the participants exceeded the time to respond. Only nine participants exceeded the 30 s to generate a response to one of the 95 stimuli presented to them. In these isolated cases, the stimulus, which was different for every case, was repeated. Reaction time was measured as the time elapsed before the response word was produced, using the chronometer included in the computer program. For a detailed review of the data, see the Appendix.

2.4 Coding and data analysis

Word associations can be analyzed from different levels of word processing (e.g., phonological or semantic), which has led to discrepant views about which level of word processing primarily drives such associations in the free word association task. For this reason, some studies have favored the use of classifications that reflect their stance on the matter (e.g., Vivas et al. 2018, used a classification focused on semantic properties). In the current study, from the different classifications of word associations (used in studies in Spanish and other languages), we adhere to a formal linguistic one, that is, a grammatical classification. Thus, types of response words were classified as paradigmatic (in this case, nouns), syntagmatic (adjectives, verbs, or adverbs), or anomalous (blank responses, when participants did not respond, or idiosyncratic responses, when participants responded with more than one word or with idiosyncratic sentences, e.g., *Mi perro se llama Max* 'My dog's name is Max'). The coding of response words was made by two trained linguists. A Cohen's kappa was run between coders for a random sample of the data (20 % of the total, 20 % per participant, $n = 1604$ words), demonstrating a high strength of agreement, $\kappa = 0.970$, $p < 0.001$.

Linear mixed-model effect (LMM) and binomial generalized mixed-model effect (binomial GLMM) analyses were performed using the lmer and confint functions from R Core Team (2020) version 4.5.0, and lme4 (Bates et al. 2015), and *p*-values were calculated using the afex package (Singmann et al. 2020). Model estimations were made using the ggpredict function from the ggeffects package (Lüdecke 2018). The semantic category of stimulus variable was sum contrasted (deviant coded), the reaction time variable was log-transformed, and the age and years of education variables were min-max normalized and centered to zero to analyze the direction of the slope given as a positive or negative increase within variables. The R scripts are in the Open Science Framework repository, https://osf.io/ptb2q/?view_only=7b41acc9f0bd460a8c3d29a5b952337a.

3 Results

Participants with atypical performance were filtered out. First, following the criteria of Callejas et al. (2003), four participants were excluded from the analysis because more than 10 % of their responses were anomalous (blank or idiosyncratic). Subsequently, two participants were excluded from analysis because they gave only paradigmatic responses. The frequency proportion of anomalous responses was less than 0.01 (M = 0.009, SD = 0.003); therefore excluded from further analysis. The analysis included a total of 4930 lexical relations.

The mean time to generate a response was M = 4.71 s (SD = 3.39 s) with a range of 0.49–59.96 s (after log transform, M = 2.01, SD = 0.72). The proportion of paradigmatic responses was higher (M = 0.58, SD = 0.24) than that of syntagmatic responses (M = 0.42, SD = 0.23). A Wilcoxon signed-rank test showed significant differences (z = –2.66, p = 0.02) between the proportions of the two types of responses.

3.1 Type of response: paradigmatic versus syntagmatic

A binomial GLMM model was fitted to determine whether the type of response (Type) was predicted by the semantic category of stimuli and to confirm that neither age nor years of education have an effect on the type of response. Considering that the organization of the mental lexicon follows semantic and grammatical contexts (Barsalou et al. 2018), the semantic category of the stimulus (Sem), and the participant's age (Age) and years of education (Education) were used as fixed factors, and the stimulus (Input) and participant (ID) as random effects. Age and Education were considered as fixed factors in order to confirm that these variables did not have a within-subjects effect (see Burke and Peters 1986; Hirsh and Tree 2001).

Table 1: Fixed effects parameters of GLMM.

Fixed Effects of Model: Type ~ Sem + Age + Education + (1| Input) + (1| ID)				
	Estimate	**Std. error**	***z*-value**	***p*-Value**
(Intercept)	0.1876	0.2553	0.735	0.4625
Animals	0.7295	0.1707	4.273	< 0.0001***
Places	−0.1306	0.1959	−0.666	0.5052
Tools	−0.2407	0.1750	−1.376	0.1690
Inanimate familiar objects	−0.3053	0.1824	−1.674	0.0942
Age	−1.6779	1.0283	−1.632	0.1027
Years of education	−0.7757	0.8174	−0.949	0.3426

***$p < 0.001$.

The GLMM equation was Type ~ Sem + Age + Education+ (1| Input) + (1| ID). Given that the semantic category Food showed relatively stable patterns in preliminary data exploration, it was used as a reference level. Within the fixed effect Sem, the semantic category Animals has large effect slopes below the significance level (alpha = 0.05; see Table 1). Our analysis reveals a tendency of paradigmatic responses over syntagmatic ones, and only the semantic category Animals has frequencies of response type different from the overall mean (see Figure 1). Our analysis also suggests that neither

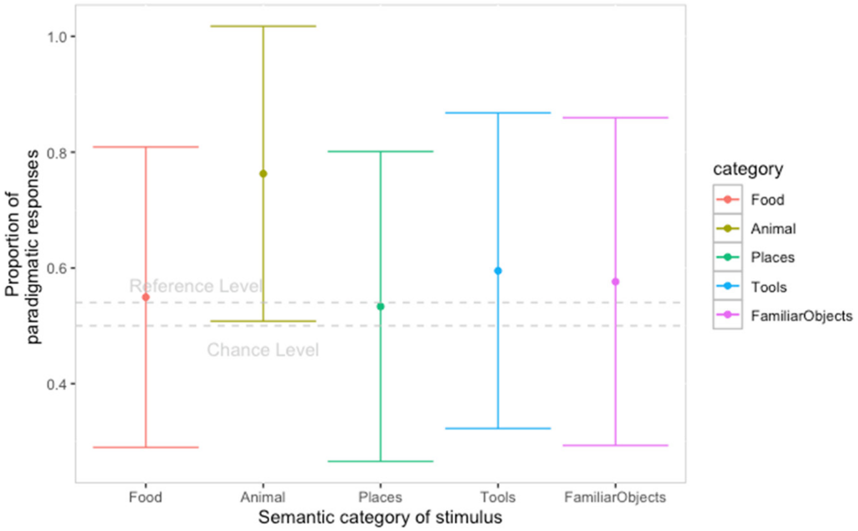

Figure 1: Proportions of paradigmatic responses (nouns) predicted by the Fixed Effects of Model: Type ~ Sem + Age + Education + (1| Input) + (1| ID). Sem = semantic category of the stimulus, A: animals, P: places, T: tools, FO: inanimate familiar objects, and F: food. Error bars represent 95 % confidence intervals (CI).

participants' age nor their years of education have an effect on older adults' response type to a given stimulus.

3.2 Reaction time

A LMM model was fitted to test for the existence of dual grammatical and semantic activation paths and to observe whether there were differentiated reaction times (RT) based on the type of response and the semantic category of the stimulus. The type of response (Type), the semantic category of the stimulus (Sem), the participant's age (Age), and years of education (Education) were considered as fixed factors, while stimulus (Input) and participant (ID) were considered as random effects. To confirm that neither Age nor Education have an effect on the variance of RT, these variables were modeled as fixed effects.

The LMM equation was RT ~ Type*Sem + Age + Education+ (1| Input)+ (1| ID). Given that the semantic category Food showed relatively stable patterns in preliminary data exploration, again, it was used as a reference level for consistency and comparability across analyses. Within the fixed effect Type, paradigmatic responses showed slopes below the significance level (alpha = 0.05). Within the fixed effect Sem, we found that Animals and Places showed slopes below the significance level. Only the interaction between paradigmatic responses and Animals showed a slope below the significance level (alpha = 0.05; see Table 2 and Figure 2).

This analysis showed that reaction times are influenced by the perceived semantic category of the input stimulus and by participants' type of response. We only

Table 2: Fixed effects of linear mixed-effects model.

Fixed Effects of Model: RT ~ Type*Sem + Age + Education + (1| Input) + (1| ID)				
	Estimate	**Std. error**	***t*-value**	***p*-Value**
(Intercept)	2.003	0.068	29.348	< 0.0001***
Paradigmatic	0.052	0.010	4.953	< 0.0001***
Animals	0.188	0.032	5.833	< 0.0001***
Places	−0.110	0.036	−3.006	< 0.001**
Tools	−0.029	0.032	−0.906	0.367
Inanimate familiar objects	0.018	0.034	0.532	0.595
Paradigmatic: Animals	−0.051	0.018	−2.832	0.004**
Paradigmatic: Places	0.018	0.020	0.898	0.369
Paradigmatic: Tools	0.025	0.017	1.432	0.152
Paradigmatic: Inanimate familiar objects	0.018	0.018	1.001	0.317

**$p < 0.01$, ***$p < 0.001$.

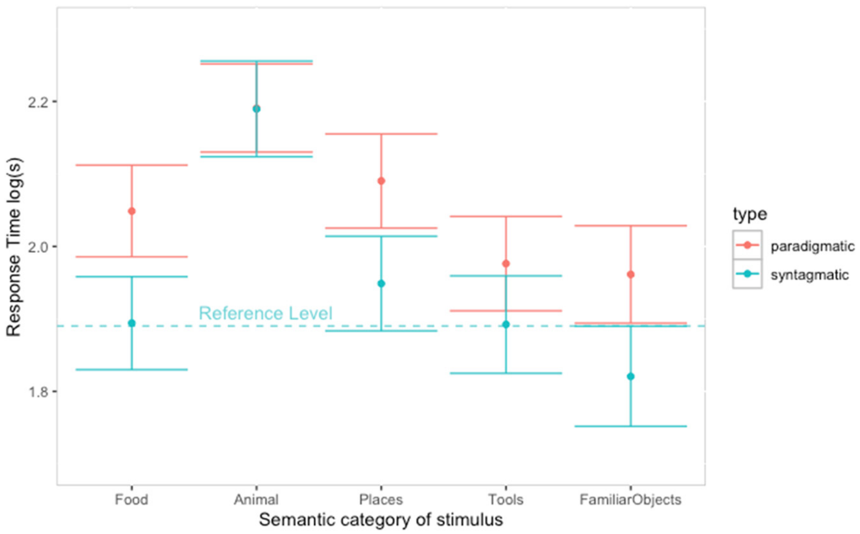

Figure 2: Reaction times (log) for fixed effects interaction predicted by the LMM: RT ~ Type*Sem + Age + Education+ (1| Input)+ (1| ID). Sem = semantic category of the stimulus, A: animals, P: places, T: tools, FO: inanimate familiar objects, and F: food. Error bars represent 95 % confidence intervals.

found an interaction between Animal and Type of response; this result also suggests that the paradigmatic and syntagmatic paths are equally relevant to this particular semantic category. Reaction times in responding to a stimulus were not affected by either age or years of education in older adults.

4 Discussion and conclusions

We aimed to examine the routes of lexical relations in Mexican Spanish-speaking older adults, using a free word association task to identify a differentiation in grammatical and semantic organization in the spreading activation of their mental lexicon. The focus of our study was on the mental lexicon of older adults – a population with a wide vocabulary – in order to break down the particularities of its complex organization. We analyzed differences in reaction times according to the type of lexical relation and assessed whether the semantic category of the stimulus influenced this relation. We found that in a word association task with nouns as stimuli, older adults gave more paradigmatic responses (responses that are of the same grammatical class as the stimulus, in this case nouns) than syntagmatic ones (responses from a different grammatical class than the stimulus, in this case, adjectives, verbs, or adverbs), and that paradigmatic responses also required greater reaction times. We also found, like Callejas et al. (2013), that the semantic category of the stimulus influenced the type of lexical relation, and that reaction times were influenced by both the semantic category and the type of lexical relation. Semantic information has a relevant impact on the type of responses generated in the word association task; it is probable that the type of grammatical response (e.g., noun, verb, or other) is mediated by the type of semantic relation that each semantic category of stimuli establishes with its response. This result indicates that both semantic and grammatical information from a word affect the type of response and reaction times in a free word association task.

Our results are consistent with those of other studies (e.g., Burke and Peters 1986; Flores-Coronado et al. 2019; Minto-García et al. 2020), indicating that in a free word association task, older adults generally provide more paradigmatic than syntagmatic responses. This preference for paradigmatic responses can be explained in two ways. First, paradigmatic relations may be more stable at this stage of development. Given that nouns have an acquisition bias in Spanish (Dhillon 2010; Gentner 1982), it is probable that older adults' lexical repertoire is primarily formed by this grammatical category. Thus, it can be inferred that nouns (which in this study reflect paradigmatic responses) are strongly related to one another. The second explanation concerns the frequency of the grammatical category of the stimulus that encourages a particular type of response. It has been found that nouns generate mainly paradigmatic responses (De Deyne and Storms 2008; Goldfarb and Halpern 1984; Nissen and Henriksen 2006). The stimuli of our free word association task were all nouns; for this reason, it is possible that older adults, listening to a succession of nouns, preferred to respond with more nouns than other grammatical categories. A future study using stimuli from other categories could test this hypothesis.

Our analysis demonstrates that the semantic category of the stimulus word also influences lexical relations. This finding indicates that the activation of the mental lexicon follows both a semantic criterion and a grammatical one. This result is consistent with Norvig (1989), who argues that the meaning of a word is in part constrained by the grammatical characteristics of the adjacent lexical elements; thus, in a free word task, participants might recall the grammatical category prototypically associated with the meaning of the stimulus word. Furthermore, these lexical activations may be dictated by the embodied lexical language contexts (Barsalou et al. 2018). Our result is consistent with the findings of Callejas et al. (2003), who identified differences in the homogeneity of the stimuli according to their semantic category, which entails different patterns in the association of words in Spanish. Our mixed-effects analysis showed that the semantic category of the stimulus has an effect on the type of lexical relation generated by older adults; that is, the semantic category of the stimulus influences the type of response. Meaning is grounded in sensory embodiment and its context; embodied experience regarding different semantic stimuli affects the type of response. It is more feasible, for example, for an animal to be an agent and for a tool to be a grammatical object. The structure of lexical networks in aging is thus also determined by the perceived meaning of words. In our data, neither age (60–80 years) nor education (3–19 years) significantly influenced how the words are organized or their relationships to one another. It was expected that age would have no effect (see Burke and Peters 1986; Hirsh and Tree 2001), indicating that the lexical relation process is stable at least over different stages of aging. Lexical relations evidenced in aging are thus determined by semantic and grammatical contexts.

Our results suggest that the mental lexicon is organized into semantic clusters interconnected by grammar – that is, semantic hubs that are dependent on the semantic category of the stimulus – while the strongest links between words appear to be grammatical. As a result, when a lexical node (a word) is activated, the propagation tends to flow through the semantic cluster, and even if it is predisposed to remain within the same cluster, the hub's interconnectivity could bias the activation to a different cluster – probably as a result of speech regularities, that is, of grammatical context (Osgood and Sebeok 1965). The interference between grammar processing and semantics shows that such dual path activation propagation is necessary to extract meaning from speech.

Our analysis also demonstrates that reaction times in older adults are influenced neither by age nor by years of education, but by both the semantic category of the stimulus and the type of lexical relation generated. Age had no within-subjects effect, which indicates that differences in reaction times were not due to an age-related decay (as pointed out by Ramscar et al. 2014, 2017). Our results suggest that reaction times in this free word association task of older adults depended on the semantic category of the stimulus and the grammatical relation of the response; that is, they depended on the speaker's own lexical repertoire. Given that vocabulary peaks in old age, older adults have a broader lexical repertoire than younger adults (see Brysbaert et al. 2016; De Deyne et al. 2019; Zortea et al. 2014). Because older adults' vocabulary includes a large number of words, it is possible that some of these words are in clusters with others in the same semantic category. Accordingly, a stimulus word of a certain semantic category could be linked with many others that compete for selection (as it holds on to the competition effect in the spreading activation model by Collins and Loftus 1975) in a word association task, so choosing a suitable response takes longer.

The analysis of reaction times revealed that although paradigmatic (noun-noun) responses were more frequent, participants were generally slower when giving paradigmatic responses (see, for example, the responses generated by the semantic category of Places in Figure 2). However, reaction times were obtained in the syntagmatic responses between semantic categories (as in the responses generated by Places and Food in Figure 2). In addition, the lack of interaction in reaction times between most semantic categories and the type of response suggests that the time difference between paradigmatic and syntagmatic responses is due to the grammatical category of the stimuli (nouns). It is thus possible that the size of the cohort of the noun paradigm, an always-growing category, entails a greater cognitive effort to produce a response. However, more research is needed to explain why the propagation of activation by free word association remains within the same grammatical category even when longer reaction times suggest that it is difficult to choose a lexical response.

In our analyses of both the binomial GLMM model and LMM model, Food was selected as the reference category to facilitate interpretation of the model coefficients. Compared to the other semantic categories – Animals, Places, Inanimate Familiar Objects, and Tools – Food was among the most consistently represented across participants and showed relatively stable patterns in preliminary data exploration. Choosing Food as the reference level allows for meaningful comparisons, as it represents a semantically coherent and concrete category with everyday relevance. However, it is important to note that all coefficients in both models reflect differences relative to Food. Thus, any apparent effects should be interpreted in this comparative context. Future studies may explore alternative reference levels to assess the robustness of these effects across different baselines.

In the Animal category, reaction times for paradigmatic and syntagmatic responses were not differentiable. This particularity could be related to the category being one of animate objects, whereas the objects of the other categories were all inanimate. These distinctions may imply that speakers have different word-context expectations based on embodied experiences. Another explanation involves the kind of semantic features that are relevant for each semantic category of stimuli during our bodily interactions. For instance, animals as active agents, are most often passively associated and learned with their perceptual characteristics (e.g., a striped zebra, a running cheetah, a gray elephant) or their inherent characteristics as living beings that embody actions (e.g., moving, eating, breathing, flying). This implies a strong connection between the animal and its features or its actions, generating a syntagmatic relationship (e.g., adjectives or verbs as responses). Animals are also easily classified into other noun categories (e.g., dog-animal; cat-pet; spider-insect), and the links between them probably strengthen with age. Some studies have shown that older adults tend to prefer categorical relations, such as superordination (Smiley and Brown 1979), that imply a paradigmatic relation (e.g., dog-animal). The broad knowledge of the lexicon that older adults obtain through cumulative linguistic experience (Ramscar et al. 2017) could explain why stimuli from the Animal category involve similar effort for syntagmatic and paradigmatic responses.

It is plausible that semantic and grammatical processes in this category compete on equal terms, that is, that reaction times are similar in both syntagmatic and paradigmatic relations.

The present study provides novel evidence, not only about the type of response according to the semantic category of the stimulus, but also regarding the reaction time of the response in late adulthood. It shows that the lexicon is arranged according to semantic and grammatical information. Given the broader linguistic experience of older adults, the emergence of more lexical competitors is inevitable. Further research along these lines would allow us to explore the impact of aging on the fitness of propagation within the lexical network.

Several studies have reported deficits (such as information retrieval problems) evidenced in the performance of semantic tasks (e.g., Burke and Shafto 2004; Hoffman and Morcom 2018), even when semantic memory is preserved (e.g., Caplan and Waters 2005; Verhaeghen and Salthouse 1997). A discrepancy has been found between the production of older adults and their understanding of words (James and MacKay 2007). This difference has been explained by the transmission deficit hypothesis (Burke et al. 2000). Another possible cause for the transmission deficit is the decrease in the performance of the working memory system, which holds small amounts of information for manipulation (Luo and Craik 2008) and generates a general slowdown in mental processes, affecting language as well (Caplan and Waters 2005; Verhaeghen and Salthouse 1997). Our study of the lexical relations generated in a free word association task allowed us to observe that the processes that work within specific semantic and syntactic clusters in the mental lexicon also impact the time needed to generate a response associated with a stimulus.

Our study has some limitations. Participants were categorized with typical aging according to a sociodemographic self-report they answered before beginning the experiment, but this information was not confirmed with psychometric testing. Future studies should assess cognitive abilities with a screening instrument to confirm the absence or presence of neurodegenerative diseases. Another limitation was the absence of a vocabulary-level measure, which would have allowed for verification of participants’ lexical repertoire and enabled further analyses of vocabulary breadth and response times. Additionally, following ongoing discussions concerning the levels of language processing engaged in word association (see Vivas et al. 2018), we recognize that our linguistic classification of the type of lexical relations – into paradigmatic and syntagmatic types, a classification attached to formal linguistics – may involve semantic overlap. Finally, our study analyzed dual path lexical activation; however, our results may be highly influenced by the morphological structure of Spanish which could affect the relevance of grammatical and semantic paths during word association, especially when compared with highly lexicalized languages, such as English, or with more morphologically rich languages, such as Dutch.

In sum, this study examined how Spanish-speaking older adults produce lexical relations through a free word association task. We found a differentiated grammatical and semantic organization in the mental lexicon of older adults based on language contexts, with a dual path spreading activation. Based on our findings, we hypothesize that processing speed is not always associated with a decline in language processing. Our data suggest a relationship between the type of words (both stimulus and their response, and the connection between them) involved in the word association task and reaction time. This study reflects the complex nature of linguistic processing in older adults.

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Data availability: The data underlying the present study can be accessed under the following DOI: 10.5281/zenodo.16879838.

Appendix

Stimuli, semantic coherence classifications, and frequency of use from the Wordbank database (Frank et al. 2016).

Stimuli	Category of semantic coherence	Frequency from wordbank
alberca 'swimming pool'	Places	0.44
almohada 'pillow'	Inanimate familiar objects	0.76
araña 'spider'	Animals	0.87
ardilla 'squirrel'	Animals	0.40
aretes 'earrings'	Inanimate familiar objects	0.61
bacinica 'potty'	Tools	0.53
borrego 'sheep'	Animals	0.63
botón 'button'	Inanimate familiar objects	0.76
burro 'donkey'	Animals	0.74
cacahuate 'peanut'	Food	0.66
caja 'box'	Inanimate familiar objects	0.77
cama 'bed'	Places	0.95
carne 'meat'	Food	0.87
casa 'house'	Places	0.89
cebra 'zebra'	Animals	0.35
chocolate 'chocolate'	Food	0.87

(continued)

Stimuli	Category of semantic coherence	Frequency from wordbank
chupón ‘pacifier’	Tools	0.56
cobija ‘blanket’	Inanimate familiar objects	0.81
cochino ‘pig’	Animals	0.63
cocodrilo ‘crocodile’	Animals	0.44
collar ‘necklace’	Inanimate familiar objects	0.47
colores ‘colors’	Tools	0.69
computadora ‘computer’	Places	0.24
conejo ‘rabbit’	Animals	0.77
crayolas ‘crayons’	Tools	0.58
cubeta ‘bucket’	Tools	0.71
cuchara ‘spoon’	Tools	0.81
cuna ‘cradle’	Places	0.84
dulce ‘candy’	Food	0.89
durazno ‘peach’	Food	0.50
ejotes ‘green beans’	Food	0.35
elefante ‘elephant’	Animals	0.79
elote ‘corn’	Food	0.73
escalera ‘stairs’	Places	0.71
escoba ‘broom’	Tools	0.82
espejo ‘mirror’	Places	0.73
fresa ‘strawberry’	Food	0.61
galleta ‘cookie’	Food	0.94
guajolote ‘Turkey’	Animals	0.31
hamburguesa ‘hamburger’	Food	0.47
hielo ‘ice’	Food	0.61
hipopótamo ‘hippopotamus’	Animals	0.34
hot cakes ‘hot cakes’	Food	0.37
jabón ‘soap’	Inanimate familiar objects	0.94
jirafa ‘giraffe’	Animals	0.48
lavabo ‘sink’	Places	0.50
lavadora ‘washing machine’	Places	0.52
leche ‘milk’	Food	0.97
lentes ‘glasses’	Inanimate familiar objects	0.71
leña ‘firewood’	Inanimate familiar objects	0.26
león ‘lion’	Animals	0.69
libro ‘book’	Inanimate familiar objects	0.73
lobo ‘wolf’	Animals	0.58
mamila ‘baby bottle’	Tools	0.84
manzana ‘apple’	Food	0.84
mercado ‘market’	Places	0.74
mesa ‘table’	Places	0.92
olla ‘pot’	Tools	0.52
oso ‘bear’	Animals	0.82
paleta ‘lollipop’	Food	0.85
palo ‘stick’	Tools	0.79

(continued)

Stimuli	Category of semantic coherence	Frequency from wordbank
pastel 'cake'	Food	0.84
pato 'duck'	Animals	0.82
perro 'dog'	Animals	0.84
pescado 'fish'	Animals	0.81
plato 'plate'	Tools	0.84
pluma 'pen'	Tools	0.69
plumones 'markers'	Tools	0.69
puerta 'door'	Places	0.84
queso 'cheese'	Food	0.81
radio 'radio'	Inanimate familiar objects	0.69
rana 'frog'	Animals	0.74
ratón 'mouse'	Animals	0.71
refrigerador 'refrigerator'	Places	0.63
reja 'fence'	Places	0.37
reloj 'clock'	Inanimate familiar objects	0.74
salchicha 'sausage'	Food	0.73
silla 'chair'	Places	0.90
sofá 'sofa'	Places	0.37
taco 'taco'	Food	0.81
tambor 'drum'	Inanimate familiar objects	0.53
taza 'mug'	Tools	0.76
tigre 'tiger'	Animals	0.55
tijeras 'scissors'	Tools	0.69
timbre 'doorbell'	Inanimate familiar objects	0.55
tina 'tub'	Places	0.74
toalla 'towel'	Inanimate familiar objects	0.69
trapo 'rag'	Tools	0.60
uvas 'grapes'	Food	0.68
vaso 'drinking glass'	Tools	0.82
ventana 'window'	Places	0.77
víbora 'snake'	Animals	0.58

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