Morphological processing of complex and simple pseudo-words in adults and older adults

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Abstract

The role of morphemes in lexical recognition has been extensively explored in recent years, although the evidence from older adults is extremely scarce. In this study, we carry out a lexical decision task to assess the interference generated by morphological composition of pseudo-words (i.e., the longer and more error prone decisions on pseudo-words made up of morphemes in comparison to pseudo-words without morphological appearance) in a group of young and older adults (mean = 74 years). The results show the expected effect on both response latencies and error rates for both groups. The effect of imageability is also significant. The specific results for the older adults show an interaction between the morphological effect and cognitive reserve: older adults with higher levels of cognitive reserve are more sensitive to morphological interference than older adults with lower cognitive reserve. The overall results are interpreted based on current models of morphological processing and aging.

1. Introduction

The role of derivational morphology in visual word recognition has been the subject of considerable research in recent decades. This research has shown that morphemes play a role in visual word recognition of complex words. Although a number of aspects of morphological processing (whether its role starts early on the process, whether it affects lexical recognition earlier or later than semantic processing, etc.; see Amenta & Crepaldi, 2012) have been discussed, it is generally accepted that morphological processing has its own role in lexical recognition beyond orthographic and semantic processing.

The evidence accumulated for morphological processing during visual word recognition has mostly been obtained with adults (e.g., Diependaele, Sandra, & Grainger, 2005; Lázaro, Sainz, & Illera, 2015; Rastle, Davis, & New, 2004) but also with children with and without language difficulties (e.g., Burani et al., 2008;

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Lázaro et al., 2017, 2018; Mann & Singson, 2003; Quémart, Casalis, & Duncan, 2012).
One of the most common ways to assess morphological processing in visual word
recognition is through masked priming lexical decision experiments (50 ms prime
presentation). Typically, primes and targets are related (1) in semantic and morpho-
logical terms, as in hunter-hunt (transparent condition); (2) in morphological but not
in semantic terms, as in corner-corn (opaque condition); and (3) only in ortho-
graphical terms, as in brothel-broth (form condition). The results show the same
facilitatory effect for the transparent as for the opaque words with no benefit for the
form condition. This result has been interpreted as morphological processing taking
place early in the process without any influence of the semantic relationship between
primes and targets (e.g., Gold & Rastle, 2007; Lázaro, García, & Illera, 2021; Smolka,
Libben, & Dressler, 2019), although this pattern of results has some exceptions (see,
e.g., Feldman, O'Connor, & Moscoso del Prado Martín, 2009).

Despite the large body of evidence accumulated for morphological processing in
visual word recognition, the evidence relating morphological processing and aging is
almost nonexistent. One of the few studies on the topic is that by Reifegerste, Elin, &
Clahsen (2018). These authors explored morphological processing in healthy, bilin-
gual young and older adults in a masked lexical decision task. Reifegerste et al.
observed no interaction between age and the morphological effect observed, and it
was thus concluded that derivational processing is unaffected in aging.

On the other hand, Duñabeitia et al. (2009) carried out an experiment in Spanish.
These authors presented compound words primed by their first constituent, second
constituent, or an unrelated word, in a lexical decision task with a group of young
adults and a group of older healthy adults. The results showed that the magnitude of
the constituent priming effect was similar for young and older adults. These results
were interpreted as fully preserved morphological processing in advanced age when
two lexical morphemes appear within a word. These results are interesting for the
present study since they were collected precisely from Spanish speaking participants,
as is our case. However, the experiment by Duñabeitia et al. (2009) explored
compound processing, whereas we focus on derivational suffixes, as these are the
most frequent morphemes in Spanish. Indeed, languages differ in the way new words
are coined. For instance, Romance languages, such as Italian, French, or Spanish, tend
to create new words through derivational morphology (stems + derivational suffixes;
Rey-Debove, 1984; Varela, 1990), whereas in Germanic languages, such as Dutch,
English, or German, compounding is the most productive way (stem + stem). This
implies that speakers and readers of different languages are exposed to different
morphological systems, and therefore the results observed for one language do not
necessarily stand for others. Taking this into consideration, despite the previously
presented evidence showing preservation of morphological processing for healthy
older adults, such evidence requires further support.

The literature also includes few studies on morphological processing and demen-
tia. Nevertheless, Kavé, Heinik, & Biran (2012) and Auclair-Ouellet et al. (2016)
published two relevant studies with different conclusions. These authors focused on
morphological processing, particularly in persons diagnosed with semantic demen-
tia, the least common form of frontotemporal lobar degeneration. Kavé, Heinik, &
Biran (2012) conducted an extensive battery of linguistic tests on a Hebrew-speaking
patient, including morphological tasks, such as inflectional production (plural forms)
and comprehension (grammatical judgment), and derivational production (diminu-
tive forms and naming). The general results of the morphological battery showed the

patient continued to process the words morphologically and used this processing to carry out all the tasks proposed. Auclair-Ouellet et al. (2016) used three production and comprehension tasks to evaluate the performance of 10 French-speaking individuals with semantic dementia and a control group. Specifically, the three tasks were: (1) verb production, that is, producing verbs from given nouns; (2) matching nouns, that is, previously produced nouns had to be matched with new nouns related in meaning; and (3) a lexical decision task with verbs and pseudo-verbs presented in the first task. The results showed that, compared with the controls, the patients with semantic dementia had greater difficulty producing nouns derived from verbs (Task 1), more difficulties in matching complex words based on the agentive meaning of the suffix (Task 2), and less accuracy than healthy participants (Task 3). Hence, while the study by Kavé, Heinik, & Biran (2012) underscores the patient's preservation of morphological processing, Auclair-Ouellet et al. (2016) highlight the deterioration of this processing. It is important, however, to consider that both studies were carried out with a small number of participants and making use of different tasks, so that methodological aspects preclude us from supporting any possibility concerning morphological processing of patients with semantic dementia.

The issue of whether language processing might be a marker of cognitive decline is of great importance. Despite there being an enormous amount of research relating cognitive status and cognitive reserve to a number of cognitive skills, only a few studies have focused on language. However, Montemurro et al. (2019) reported interesting results in this respect (see also Nikolaev et al., 2019). These authors found that accuracy in name retrieval can be predicted by cognitive reserve in older adults (see also Mondini et al., 2016). Their results led them to suggest that the naming of proper nouns is an effective task in detecting early signs of dementia.

In our view, exploring morphological processing in older adults can substantially impact not only our understanding of how visual word recognition and language processing occur, but also how cognitive decline starts and evolves. Moreover, this issue is not restricted to a mere theoretical discussion, but might have a practical impact, since as discussed, complex words – words formed by at least two morphemes, are not unusual in many languages, tending, in fact, to be very common, as Booij (2002) showed for Dutch, Rey-Debove (1984) for French, and for Spanish.

As stated above, most experimental evidence shows that morphological processing occurs as a mandatory process in visual complex word recognition in children and adults, but a little is known about the case of older adults. The few studies conducted seem to provide overall support for morphological processing not being affected in healthy older adults, but, as mentioned, morphological processing has been studied with few participants and making use of very different tasks, stimuli, and languages. We believe that more evidence needs to be obtained to further support morphological processing preservation in healthy older adults. In fact, recent studies (Reifegerste et al., 2021) have shown age-related results in lexical decision tasks (Experiments 1 and 2) as a function of the type of word. These authors observed slower responses for older adults in comparison to younger adults when non-motor words (e.g., steak) appeared, although this effect did not emerge when motor words were presented (e.g., knife). Beyond the role of motor-relatedness processing in older adults, this study showed that stimuli selection plays a great role in lexical processing. This makes it clear to us that the current evidence concerning morphological processing in older adults is insufficient to support the notion that it is preserved in aging. Hence, more evidence is required.

Our study seeks precisely to contribute to this issue. To this end, we designed a lexical decision task which assesses a well-known morphological effect in adults, that is, complex pseudo-words composed of existing morphemes (e.g., tabler) take longer to process and yield higher error rates compared to simple pseudo-words containing no morpheme (holune; Caramazza, Laudanna, & Romani, 1988). This effect was subsequently reported in Italian by Burani et al. (1999), in English by Crepaldi, Rastle, & Davis (2010) and Dawson, Rastle, & Ricketts (2018), in Spanish by Carden et al. (2019), and more recently both in the visual and auditory modality by Beyersman et al. (2020) in French and German.

The explanation for this morphological effect is interesting, since a purely lexical origin cannot be postulated given that pseudo-words have no lexical representation. It seems more reasonable to suggest that during the processing of pseudo-words, readers are sensitive to morphological information, thus presupposing a morphological representation in the system. Activating this morphological information implies matching the stimulus and a stored representation, which would generate the reader's expectation of being presented with a real word. In this case, we would then be considering an activation effect at sublexical level. This activation would explain the increase in error rate in the lexical decision task (false positives) and the higher response latency in the case of pseudo-words with lexical and derivative morphemes (tabler) compared to pseudo-words with no morphological composition (holune).

This, however, is not the only possible explanation. As well as the effect of the morphological composition of pseudo-words, Dawson, Rastle, & Ricketts (2018) also found a significant effect of word imageability. Words rated as more imaginable by external evaluators yielded more errors and higher latencies compared to those with low imageability. Imageability has been defined as 'the extent to which the referent of the word evokes a mental image' (de Groot, 1989, p. 824; see Chuang et al., 2020, for further support of semantic processing of complex pseudo-words).

In theoretical terms, according to the context availability theory (Schwanenflugel & Stowe, 1989), the effect associated with imageability reflects differences in the amount of information that links semantic knowledge with each word. The semantic approach to the effect of imageability was also supported by Sabsevitz et al. (2005)) in their brain imaging study. Specifically, these authors observed a distributed, bilateral semantic memory system that responded more strongly to concrete than to abstract words. Experimental results obtained for imageability suggest there exist differences between the representation of abstract and concrete words in the lexicon (e.g., Westbury & Moroschan, 2009) and that these differences come from differences in the semantic activation of these words.

It is worth noting that, despite our experiment being initially designed to assess the role of morphological composition of pseudo-words in visual recognition, the imageability of these stimuli is a factor that is intrinsically present. Therefore, our experimental design involves not only assessing the role of morphological processing (through the morphological or non-morphological composition of pseudo-words), but also the role of semantics (through the different imageability of stimuli). This is, to our understanding, a major strength of our study, being able to unravel the role of both issues in word processing in healthy older adults. In other words, this is not a limitation of the present study, but rather it allows us to independently explore two key aspects of language processing in aging; is morphological processing preserved in

older adults? Is semantic processing, operationalized through the imageability of the pseudo-words, preserved in older adults?

2. Experiment

In this experiment, we assess, in a sample of university students and a sample of older adults, the interference generated by pseudo-words made up of real morphemes in comparison to pseudo-words without this morphological composition. The role of the semantic imageability of complex pseudo-words is also explored. In the specific case of older adults, we also explore the role of age, cognitive reserve, and cognitive status in relation to the experimental effect assessed.

3. Method

3.1. Participants

The young adult sample comprised 27 university students (23 women) aged between 20 and 29, from the Complutense University of Madrid, who participated in the experiment in exchange for course credits. All participants had normal or corrected-to-normal vision.

The older adult participants were recruited from three different daycare centers of similar sociodemographic status. Two of the centers were located in the city of Madrid and one in the region of Castilla-La Mancha. All three centers were situated in medium socioeconomic status neighborhoods. The directors of the day centers were given information about the study and gave their consent for us to contact the older adults. They also gave their permission for the placement of informative posters about the study. Individuals willing to participate in the study were requested to sign a consent form. After 2 weeks, we obtained informed consent from a total of 92 patients (41 from Center 1, 16 from Center 2, and 35 from Center 3). The study was then conducted with these 92 participants (75 women and 17 men). Mean age was 74 (SD = 7.6). All participants were native Spanish speakers and spoke no other language.

A further 30 volunteers, students at the University Complutense of Madrid, rated the 'wordlikeness' of pseudo-words on a seven-point scale to enable further analyses considering this factor. These participants were individually required to complete an excel sheet with the pseudo-words in a random order and were asked to score every pseudo-word from 1 to 7 in accordance with the imageability they thought these stimuli had (1 very low imageability to 7 very high imageability). Two pseudo-words not included in the experimental set were used as examples to make the score method to these participants.

3.2. Instruments

The following materials were administered to all participants in the older adult group:

(i) The Cognitive Reserve Questionnaire designed by Rami et al. (2011), which comprises eight items measuring (1) educational level; (2) parental educational level; (3) other training courses undertaken; (4) work qualifications; (5) musical education; (6) languages spoken; (7) reading activity; and (8) participation in intellectually challenging games. The items are scored numerically on scales from

0 to 2 (Items 2, 5, and 8), 0 to 3 (Items 3 and 6), 0 to 4 (Items 4 and 7), and 0 to 5 (Item 1). The scores are summed to obtain an overall score on Cognitive Reserve over 25. The original study did not explicitly report its reliability, but the Spanish-speaking scientific community has considered it to have adequate face and content validity. Recently, Martino et al. (2021) have shown acceptable reliability for research use of the instrument ($\omega_{NL} = 0.72$) and indications of concurrent validity with the Montreal Cognitive Assessment (MoCA; $r = 0.4$, $p < 0.001$). The Cognitive Reserve Questionnaire has been successfully used in the study of language skills in older adults (López-Higes et al., 2013). Table 1 shows the overall scores on this questionnaire.

(ii) The MoCA (Nasreddine et al., 2005) is a screening assessment for examining general mental status that uses basic forms of widely validated neuropsychological tests to measure six cognitive domains. It is scored out of 30 points, and one point is added to correct for individuals with 12 years or less education. The first validation study in Spain showed a cut-off point of 21 points. (Ojeda et al., 2016). Delgado et al. (2019) showed good internal consistency (Cronbach's alpha = 0.772), very good inter-rater reliability (Spearman correlation coefficient = 0.846, $p < 0.01$), and optimal intra-rater (retest) reliability ($r = 0.922$, $p < 0.001$). The test is effective and valid for the detection of amnestic mild cognitive impairment (ABC = 0.903) and dementia (ABC = 0.957). The best-performing cut-off point for mild cognitive impairment was, again, 21 points, and 20 points for dementia, with a sensitivity/specificity of 75/82% and 90/86%, respectively. Table 1 shows the overall results for this test.

(iii) The short form of the Geriatric Depression Scale (GDS-15; Sheikh & Yesavage, 1986) comprises 15 items that assess the presence of depressive symptoms in older people. The score on this scale was used as an exclusion criterion. Participants who scored nine or more points were excluded from the sample ($n = 4$) to avoid the effect of possible emotional disorders on the process of cognitive impairment (Richard et al., 2013). The validation study of the Spanish version (Martínez de la Iglesia et al., 2012) showed and interobserver and an intra-observer reliability of weighted Kappa = 0.655 ($p < 0.001$) and 0.951 ($p < 0.001$), respectively. Internal consistency reached Cronbach´s alpha = 0.994. Convergent validity reached a Spearman correlation coefficient = 0.618 ($p < 0.001$) when comparing the GDS with another depression questionnaire, and discriminant validity was confirmed by a low Spearman correlation = 0.235 ($p < 0.001$) between the GDS and a cognitive screening task. Table 1 shows the overall results on this test.

All of the questionnaires were administered in accordance with their respective instruction manuals.

Table 1. Results for participants' scores on each test

	Mean	SD	Range
Age	74.1	7.6	58–94
MoCA	21.2	4.8	8–29
Cognitive Reserve	8	4	1–21
GDS	2.8	2.1	0–8

Abbreviations: GDS, Geriatric Depression Scale; MoCA, Montreal Cognitive Assessment.

3.3. Stimuli

One hundred and sixty stimuli were created. Half were words and the other half pseudo-words. Of the 80 pseudo-words, 40 had both an existing stem and an existing derivational suffix (*aceitista*). The stems did not constitute free stems, that is, there were no words by themselves (*'aceit'* is the base for the pseudo-word *'aceitista'*, but it needs an *'e'* to constitute the real word *'aceite'* 'oil'). The other half had no morphological composition whatsoever (*acestefa*). The first syllable of complex and simple pseudo-words was paired one by one to ensure no role for the syllable frequency. Letter length was also controlled (mean 8.3 vs. 8.2, SD 0.8 vs. 0.6) as well as neighborhood density (this being zero). All linguistic measures were collected from the electronic EsPal database by Duchon et al. (2013)).

With regard to the words, half were polymorphemic, whereas the other half were monomorphemic (see the Appendix).

3.4. Procedure

A lexical decision task was conducted. The experiment was programmed using the DMDX software package (Forster & Forster, 2003). Participants were instructed to judge as quickly as possible whether the presented letter strings were real words or not, while avoiding errors. Participants sat about 50 cm from a laptop screen in a quiet room. The screen showed a fixation point '+' for 1 s, followed by a word or nonword target for 1.5 s for young adults and 4 s for older adults or until participants responded. After a response or time out, a blank screen was displayed for 500 ms. The order of presentation of the stimuli was randomized.

Prior to the experiment, 10 trials were presented in this same manner. None of these stimuli presented in this training session was used in the experiment.

4. Data analysis

We performed three different analyses. In the first analysis, we examined the interference effect generated by suffixes of complex pseudo-words by comparing the latencies and errors rates of young and older adults. In the second analysis, we explored the role of imageability in the same age groups. Lastly, in the third analysis, we focused on older adults and explored the role of age, cognitive reserve, and cognitive status.

The latency analysis was applied to 27 young adults (2,160 observations) and 92 older adults (7,360 observations) and 80 items. Before the latency analysis is carried out, we eliminated observed errors (19.17% (414 observations) for young adults and 26.41% (1,944 observations) for older adults) and correct response latencies below 200 ms (0 observations) for young adults and 0.2% (15 observations) for older adults.

In the first analysis, the response latencies were analyzed using linear mixed-effects (LMEs) models in R (version 4.1.0 (2021-05-18), R Development Core Team) using the lme4 package (version 1.1-27.1; Bates et al., 2015). We fit the maximal random effects model (Barr et al., 2013) with Age (young/old adults; sum coded: −1, 1) and PseudowordType (complex/simple; sum coded: −1, 1) as fixed effects; random intercepts for participants and items and random slopes by PseudowordType for participants as random effects, with log latencies to comply with

the requirement of normality of model residuals. The errors were analyzed using mixed logistic regression model.[1]

The *p*-values of the inferences on the parameters of the model were obtained using the lmerTest package (version 3.1-3; Kuznetsova et al., 2017) with Satterthwaite approximation for degrees of freedom.

The imageability factor was not incorporated into the model because the differences between the scores on simple pseudo-words (mean = 1.04) and complex (mean = 2.6) were significant ($t(29) = 10$, $p < 0.001$), and hence the imageability factor could be confounded with the pseudo-word type if they were incorporated into the model in conjunction. To avoid this, we conducted the analysis separately, subsequently finding the specific effect of imageability on the processing of complex pseudo-words.

The imageability effect was analyzed in the second analysis only for complex pseudo-words using LME, with Age (young/old; sum coded: −1, 1) and Imageability (mean centered) as fixed effects, and random intercepts for participants and items as random effects.

For the third analysis, we initially examined a model with four fixed effects: two continuous variables and two categorical variables. The two continuous variables were Age (mean centered) and Cognitive Reserve (cogRes, mean centered); the categorical variable was PseudowordType with two levels (complex/simple; sum coded: −1, 1), and General Cognitive Status (MoCa) with two levels (low/high, with 'high' implying MoCa > 21 and 'low', MoCa < 21; sum coded: −1, 1). First, we fit a model with these four factors, and all the 2-, 3-, and 4-level interactions as fixed effects and random intercepts for participants and items and random slopes by PseudowordType for participants as random effects. As there were no significant interactions with Age, we subsequently analyzed a model with Age as additive effect. We report the result of this model. We used log latencies to meet the requirements of normality for the model residuals.

5. Results

The results show a main effect of PseudowordType ($t = -5.947$, $p < 0.001$), by which simple pseudo-words elicited faster responses than complex pseudo-words. There is also a main effect of Age ($t = 10.259$, $p < 0.001$), showing faster responses for young adults than for older adults. Interestingly, there is no interaction between these variables ($t = -0.078$, $p = 0.938$), thus showing that the morphological effect explored is not reduced in older adults (see Fig. 1).

With regard to the error rates, the results show a main effect of PseudowordType ($z = -11.891$, $p < 0.001$), by which complex pseudo-words elicited more errors than simple pseudo-words. There is a lack of significance for Age ($z = 1.527$, $p = 0.127$), as well as for the interaction between the variables ($z = 0.584$, $p = 0.559$; see Table 2).

In the second analysis, the results revealed no effect of Imageability on response latency ($t = 1.577$, $p = 0.115$), but an unsurprising significant effect of Age ($t = 6.492$, $p < 0.001$). The interaction did not reach significance ($t = -1.577$, $p = 0.115$).

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[1]R packages version numbers used for the present analysis: tidyverse 1.3.1, plyr 1.8.6, lme4 1.1-27.1, lmerTest 3.1-3, Hmisc 4.5-0, effects 4.2-0, and devtools 2.4.3.
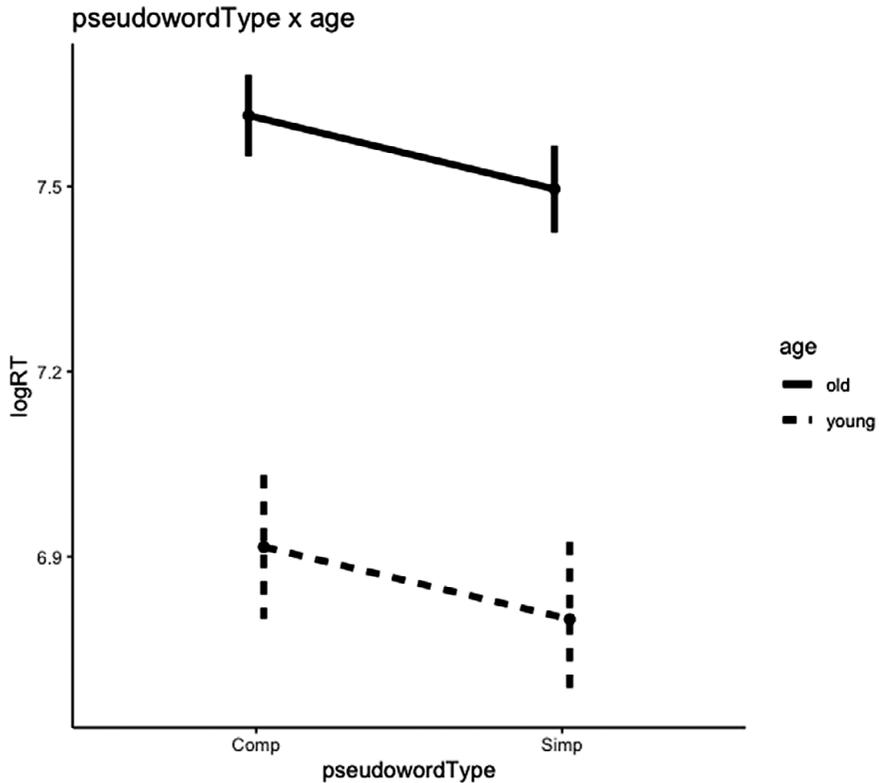
Fig. 1. PseudowordType × Age interaction.

Table 2. Mean response latencies and errors for PseudowordType

	Simple		Complex	
	RT (ms)	Errors (%)	RT (ms)	Errors (%)
Young adults	941 (47)	7.1 (1.4)	1,060 (52)	31.8 (4.0)
Older adults	1,991 (68)	13.4 (1.9)	2,187 (67)	39.5 (2.7)

Note: RT (ms) and errors (%) in parentheses.

In the analysis of error rates, the effect of imageability was not significant ($z = -0.026$, $p = 0.978$), nor the effect of Age ($z = 0.480$, $p = 0.631$) as well as the interaction ($z = 0.026$, $p = 0.978$).

In the analyses of older adults, the effect of MoCA was marginally significant ($t = -1.805$, $p = 0.074$); participants with high MoCA scores responded faster than participants with low MoCA scores. The effect of cogRes was significant ($t = -3.436$, $p < 0.001$), with higher cogRes scores resulting in faster responses. The effect of PseudowordType was significant ($t = -5.977$, $p < 0.001$). Complex pseudo-words required longer response latencies than the simple ones. The double interaction cogRes PseudowordType was significant ($t = -2.976$, $p = 0.004$). No other interaction was significant (see Fig. 2).
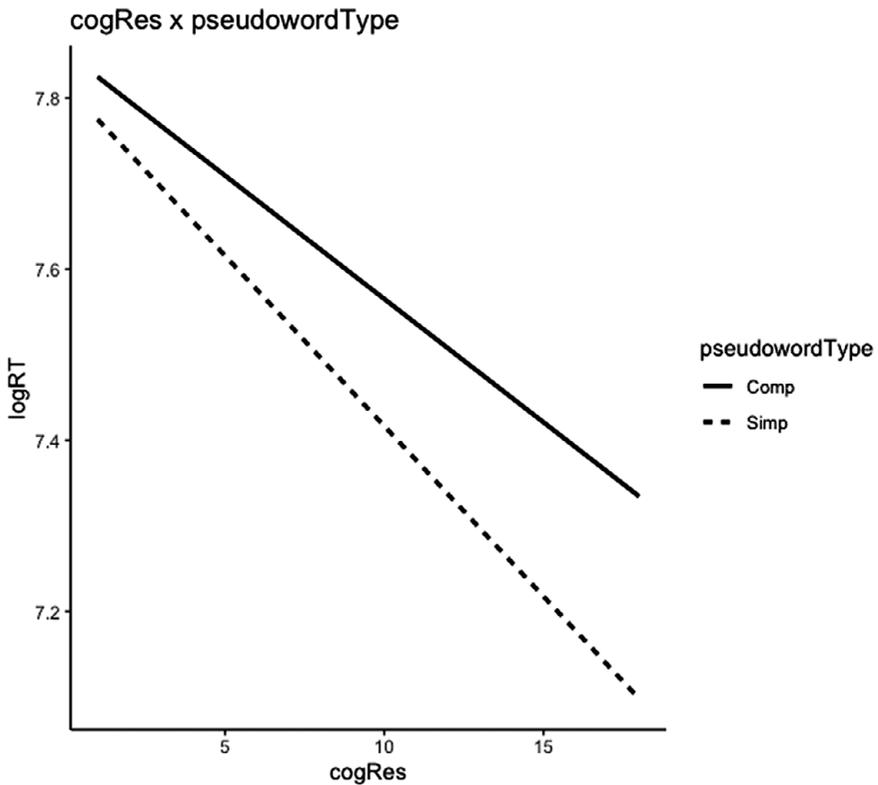
cogRes x pseudowordType

Fig. 2. PseudowordType × Cognitive Reserve interaction.

In the error analysis, we found a significant effect of Age ($z = 2.086$, $p = 0.037$), showing more errors for older adults. We also found a significant effect of MoCA ($z = -4.038$, $p < 0.001$), by which participants with higher scores presented fewer errors than those with lower scores. Furthermore, the effect of PseudowordType was also significant ($z = -11.219$, $p < 0.001$), showing that more errors were made in the lexical decision task on complex pseudo-words than on simple ones. None of the interactions were significant.

6. Discussion

In this study, we carried out an unprimed lexical decision tasks with young and older adults. Previous studies with young adults have reported that complex pseudo-words (made up of stems and derivational suffixes) generate more false positives and require more time to be responded to than simple pseudo-words (a pseudo-word with no morpheme at all; e.g., Burani et al., 1999; Crepaldi, Rastle, & Davis, 2010; Dawson, Rastle, & Ricketts, 2018). By making use of this kind of pseudo-word in this experiment, we aimed to explore morphological processing in older adults – since evidence in this regard is very scarce (see, however, Duñabeitia et al., 2009; Reife-gerste, Elin, & Clahsen, 2018) – as well as the role of semantics, operationalized through the imageability of the stimuli. Previous evidence has shown that, for young

adults, more imageable pseudo-words require more time to be rejected than less imageable ones (Dawson, Rastle, & Ricketts, 2018), but once again the evidence for older adults is scant.

The results of the experiment replicate previous ones showing that pseudo-words made up of morphemes take more time to be rejected – and are more error prone – than pseudo-words without this morphological appearance. This result can be interpreted, as in the previous literature, by considering that despite complex pseudo-words having no representation in the lexicon, their morphemes are activated during stimuli recognition. At a theoretical level, it is not challenging to explain how a complex word can activate its base. However, the evidence of complex pseudo-words activating their stems is limited and is restricted to priming studies (e.g., Hasenäcker, Beyersman, & Schroeder, 2016; Morris et al., 2010; Longtin & Meunier, 2005). In the case of complex pseudo-words, lexical activation cannot be suggested, since pseudo-words are not represented at this level, so the explanation seems to be more reasonable in terms of orthographic or morphological activation at the sublexical (e.g., Lázaro, Illera, & Sainz, 2018) or lemma level (Taft & Nguyen-Hoan, 2010). For instance, in the lemma level, Taft & Nguyen-Hoan (2010) found that the orthographic processing of the input, word, or pseudo-word detects the letters that constitute stems and derivational suffixes. From this orthographic processing, the lemmas for the stems and the suffixes are activated, and from these lemmas, the activation reaches the semantic level, although in the case of pseudo-words no lemmas are activated, but only for the morphemes they are made up of – stems and derivational suffixes.

Importantly, the results of our experiment also show that the magnitude of the morphological effect is not reduced in older adults in comparison to younger ones. Therefore, our results suggest that morphological processing is preserved in aging (e.g., Duñabeitia et al., 2009; Royle et al., 2019) which was one of the goals of this study. Consequently, we interpret that our results strongly suggest that morphological processing is unaltered in normal aging.

The results also reveal the influence of imageability of the pseudo-words. In the case of the simple pseudo-words, our external evaluators gave them a mean score of 1.04 on a scale from 1 to 5, indicating that, in their view, they are practically uninterpretable. The case of the complex pseudo-words is, however, different, since the mean score awarded was 2.6 over 5, which suggests a certain degree of imageability. Thus, it can be affirmed that the complex pseudo-words are more interpretable than their simple counterparts. This fact complicates the simultaneous statistical analysis of the variables of morphological composition and imageability, so we opted for an analysis of the effect of imageability restricted to the case of complex pseudo-words. Our results showing a significant effect of imageability in the error rates not only suggest that the task of rejecting complex pseudo-words involves sublexical activation of morphemes, but also that this activation is extended to the semantic level, as we have already explained, following the model by Taft & Nguyen-Hoan (2010) (see also Bölte, Schulz, & Dobel, 2010, or Levy, Haggort, & Dèmonet, 2014, for MEG studies related to morphological and semantic processing). Semantic activation is not incompatible with morphological activation, but is arguably the result of the latter type of activation, since semantic activation might be a direct consequence of the activation of morphemes at a lower level (e.g., Longtin, Segui, & Halle, 2003; Rastle, Davis, & New, 2004). Thus, we interpret that during the processing of complex pseudo-words, morphemes are first activated (generating the interference by which

complex pseudo-words are less easily rejected than simple pseudo-words) and subsequently the semantic representation of these morphemes and even of the possible activated lexical candidates occurs. It is true, however, that semantic activation might precede the activation of morphemes (e.g., Giraudo & Grainger, 2003), although this possibility has recently received a little support in the literature. Our results cannot deny this possibility, but our data are clear in highlighting that both morphemic and semantic influence play a role in the results obtained. The task of rejecting complex pseudo-words is thus morpho-semantic in nature and can therefore be affected in certain kinds of dementia. This would be of great significance for clinicians. Does this imageability effect exist in patients diagnosed with Alzheimer's disease? What occurs in patients with semantic dementia? These are open questions for future research.

In addition, the results for older adults reveal that individuals with high scores on the MoCA and cogRes respond more quickly on the task than those with lower scores. The effect of MoCA was also significant in the error analysis, showing that participants with higher cognitive status committed fewer errors than participants scoring lower. Furthermore, the results in the response latencies show a significant interaction between cogRes and PseudowordType. As can be seen in Fig. 2, this interaction shows that the morphological effect (the difference between latencies of simple and complex pseudo-words) is larger for participants with high cognitive reserve than for participants with low cognitive reserve. From this result, we interpret that the larger effect for participants with higher cognitive reserve reflects better functioning than for participants with lower cognitive reserve. In other words, the results seem to suggest that the higher the cognitive reserve, the greater is an individual's ability on the task. In our view, these results reflect that cognitive reserve provides more than a general approach to cognitive efficiency, because it also affects language processing itself (Montemurro, Jarema, & Mondini, 2021; Opdebeeck, Martyr, & Clare, 2016).

Importantly, the lack of interaction between age and cognitive status with PseudowordType reinforces the idea that morphological processing is preserved in aging, as already highlighted. The fact that the morphological effect explored appears in participants with low cognitive status (see Table 1) points to the preservation of morphological processing, as the lack of interaction for Group × PseudowordType suggested. Therefore, our data indicate that older adults are sensitive to morphological composition of complex pseudo-words and that this effect is modulated by their cognitive reserve.

7. Conclusions and limitations of the study

The results of this study show that older adults perform morphological processing of complex stimuli in the same way as young adults do (see Duñabeitia et al., 2009, or Royle et al., 2019). For this reason, the interference of real stems and real suffixes in rejecting pseudo-words as possible words in a lexical decision task is present in older adults as it is in young adults.

The results further show that this is true even in a group in which there are participants scoring low on the MoCA and cognitive reserve. Our interpretation is that these results evidence preserved morphological processing in aging. Nevertheless, it does not mean that the effect is the same for every participant, or that it is independent of cognitive functioning. Our data suggest that the ability to process

morphemes is related to cognitive reserve (see Stern et al., 2003). We believe that our results underpin future research with the participation of persons in the early stages of dementia in order to assess and further explore whether morphological processing is preserved in these persons. This is in fact one of the limitations of the study, that is, the lack of a group of participants with dementia to compare with the healthy older participants. We expect that our data supporting morphological processing preservation in older adults will not hold for persons with dementia, but specific evidence is clearly required.

Data availability statement. We offer full access to the R code used as well as to the raw data collected through this link https://figshare.com/s/ece8fa16950f01a54587.

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Appendix. Experiment stimuli

Complex pseudo	Simple pseudo	Complex words	Simple words
Frutista	Frudirto	Mordedura	bandido
Pescadez	Pesfotra	Moralidad	cerebro
Flautura	Flarosde	Cargador	terapia
Habiteza	Hamotredo	Corredor	candelabro
Piernista	Colaspro	Creador	serpiente
Aceitista	Acestefa	Embajador	sensato
Mantecura	Manrose	Fortaleza	estribor
Viajista	Viamenda	Atracador	mascota
Tintista	Tinvoleso	Guerrero	moqueta
Puñadal	Pusolerud	Habilidad	mortadela
caldismo	Calmoste	Nobleza	capataz
quesista	Queladojo	Repartidor	catapulta
trampura	Tramburo	Devastación	eminente
inventero	Ingoste	Papeleta	travesía
ruinista	Ruipelta	Utilidad	temperatura
orejista	Oretadeso	Vivienda	tormenta
montañez	Montalso	Absolución	chocolate
armoniero	Narloter	Acelerador	bulevar
cucharoso	Cupolesa	Armadura	menester
piscinoso	Pismuro	Aspereza	monasterio
edificiero	Edigotra	Cigarillo	pistacho
ayudero	Ayumesta	Goleador	termita
bañadal	Baleroto	Crudeza	silencio
ruedismo	Ruelister	Curvature	plástico
pensadista	Penjiste	Desnudez	licencia
obrista	obristoda	Escasez	próstata
cabecista	caremifla	Firmeza	mostacho
camarismo	cabucoda	Indicador	migraña
librista	liproste	Legalidad	cabestro
cocinismo	comupler	Maquinaria	croqueta
limpiero	limpotra	Matanza	laberinto
mentirista	mengaco	Narrador	dinosaurio
espaldismo	esbaliso	Pasajero	monstruo
telefonal	tegrecala	Pesimismo	jeringa
boquista	bolezadol	Poniente	proteína
letrura	legrasbo	Mensajero	cacharro
lechista	lemorjatro	Vestidor	alcornoque
pianeza	ojilosga	Lavadero	ventresca
palacista	palipetu	Tenista	vorágine
fresista	fredater	Patinaje	pirámide