anales de psicología / annals of psychology
2024, vol. 40, nº 3 (october), 443-457
https://doi.org/10.6018/analesps.539801

ISSN online: 1695-2294.
https://revistas.um.es/analesps

Age/Order of Acquisition influences at early stages of visual word processing: Evidence from homophonic formal priming in Spanish and English

Miguel Á. Pérez-Sánchez[1,2,*], Javier Marín[1], and Cristina Izura[2]

[1] *Universidad de Murcia (Spain)*
[2] *Swansea University (United Kingdom)*

Título: Influencias de la edad/orden de adquisición en las primeras etapas del procesamiento visual de palabras: indicios del *priming* formal homofónico en español e inglés

Resumen: Las palabras aprendidas primero o más temprano en la vida se procesan más rápido, con mayor precisión y son más resistentes a lesiones cerebrales que las palabras aprendidas en un momento posterior. Este es el efecto de la edad de adquisición (EdA). Las explicaciones actuales de la EdA sitúan su influencia en el sistema semántico –la hipótesis semántica– o en las conexiones irregulares formadas entre las representaciones –la hipótesis del mapeo arbitrario. En este estudio probamos las predicciones derivadas de estas hipótesis sobre el reconocimiento visual de palabras utilizando un paradigma formal de enmascaramiento *priming* con un SOA corto (43 ms) y dos tareas de decisión léxica: una en español y otra en inglés. Se manipularon la EdA de las palabras *target* y la relación ortográfica y fonológica entre los *primes* y los *targets*. Los resultados de los análisis con LMM mostraron efectos principales de la EdA y del *priming* fonológico, y una interacción donde el *priming* fonológico solo afectó el reconocimiento de palabras adquiridas tardíamente. Ni la hipótesis semántica ni la del mapeo arbitrario explican completamente estos hallazgos. Se discuten explicaciones alternativas como la hipótesis de la completitud fonológica o la hipótesis sensoriomotora.
Palabras clave: Edad de adquisición. *Priming* enmascarado. Fonología. Reconocimiento visual de palabras. Profundidad ortográfica.

Abstract: Words learned first or earlier in life are processed faster, with more accuracy, and are more resistant to brain injury than words learned some time later. This phenomenon is called the age-of-acquisition (AoA) effect. Current accounts of the AoA effect place its influence in the semantic system (i.e., the semantic hypothesis), or in the irregular connections formed between representations (i.e., the arbitrary mapping hypothesis). In this study, we tested the predictions derived from these hypotheses on visual word recognition using a formal masked priming paradigm with short SOA (43 ms) and two lexical decision tasks: one in Spanish and one in English. The AoA of the target words and the orthographic and phonological relationship between primes and targets were manipulated. Results from LMM analyses showed the main effects of AoA and phonological priming and an interaction where phonological priming affected only the recognition of late-acquired words. Neither the semantic nor the arbitrary mapping hypotheses fully explain these findings. Alternative accounts such as the phonological completeness or the sensorimotor hypotheses are discussed.
Keywords: Age of acquisition. Masked priming. Phonology. Visual word recognition. Orthographic depth.

Introduction

The order in which we learn words, objects, and faces has a lifelong impact on their processing efficiency and resistance to brain injury. Those items learned first or earlier are processed faster and are more resistant to memory loss than items learned later. This phenomenon is the so-called age-of-acquisition (AoA) effect (see Elsherif et al., 2023; Johnston & Barry, 2006; Juhasz, 2005, for a review).

An old debate around the AoA effect was whether the AoA influence on processing was genuinely because of differences in the age/order of acquisition of the stimuli or a consequence of other factors that naturally correlate with AoA (e.g., frequency of occurrence, degree of concreteness of the stimuli, and distinctiveness). However, many behavioural studies have shown the independent influence of AoA over and above the impact of other factors (Brysbaert, 2017; Cortese & Khanna, 2007; Izura et al., 2011; Pérez, 2007). Neuroimaging studies have shown that in language, for example, the effects of AoA and word frequency (a factor with the highest reported correlations with AoA), are modulated by different brain areas (Adorni et al., 2013; Fiebach et al., 2003; Yum & Law, 2019), indicating the independence and authenticity of the AoA effect.

Current and more notable debates have pondered regarding where in the system the AoA effect is located and how it works. Responses to these questions are vital to adjust existing models of spoken word recognition (e.g., Gaskell & Marslen-Wilson, 1997), word production (e.g., Levelt et al., 1999), and word reading (e.g., Coltheart et al., 2001) to better represent the structure and functionality of language processes. Current models assume a rather static organisation of the lexical system based on the type and the number of encounters that it maintains with the input. However, none of the referred models have considered the process of learning, the moment in life, or the order in which a word and its components (i.e., its phonology, orthography, morphology, and meaning) are acquired.

Although the research community has not agreed on the mechanisms and/or the representation units affected by the AoA, theories have been proposed. The *semantic hypothesis* and the *arbitrary mapping hypothesis* are the two most prevalent accounts to describe the AoA nowadays. Other hypotheses have been rejected because the available evidence did not support them or because they were not fully tested. In this study, we review the two most accepted accounts of the AoA effect and re-examine the theories we consider the most influential on current thinking.

*** Correspondence address [Dirección para correspondencia]:**
Miguel Á. Pérez-Sánchez. Facultad de Psicología y Logopedia, Edif. nº 31, Campus de Espinardo, Universidad de Murcia, 30100 Murcia (Spain).
E-mail: maperez@um.es
(Article received: 21-9-2022; revised: 21-2-2023; accepted: 13-6-2024)

The *semantic hypothesis* (also known as the *representation theory*) understands AoA as an intrinsic property of the semantic system. According to this hypothesis, the AoA affects how meanings are represented and the rules of the organisation of the system (Brysbaert et al., 2000; Ghyselinck et al., 2004). The evidence for the *semantic hypothesis* is from the observation of AoA effects in tasks where the semantic system is consulted before completion, for example, a word association task, picture identification task, or semantic categorisation task (Brysbaert et al., 2000; Dent et al., 2007).

Steyvers and Tenenbaum (2005) provided an explanation of why and how AoA influences cognitive processing in general and the organisation of the semantic system in particular. They proposed a model of semantic growth where the order of learning affects the connectivity of the network. Early learned concepts become more densely connected than late learned concepts. In addition, the number of connections provides the concept with a degree of centrality, with densely connected nodes becoming more central than sparsely connected concepts. Steyvers and Tenenbaum proposed that AoA effects result from a cognitive-access bias toward highly connected or central nodes that, by default, are accessed first.

A major limitation of the semantic hypothesis is its insufficient explanation for the AoA effects observed when processing words in a second language (Hirsh et al., 2003; Izura & Ellis, 2004). A remarkable amount of evidence has shown that the two languages of a bilingual speaker share the same semantic representations (e.g., Kroll & de Groot, 2005). Under these circumstances, if the AoA is a property of the semantic system, its influence in the first and the second language should be the same and correspond to the time when the concepts were acquired when learning the first language. However, processing words in a second language (learned after childhood) is affected by the order in which the second-language-words were learned and not the acquisition of the first language words or their concepts (Hirsh et al., 2003; Izura & Ellis, 2004).

The *arbitrary mapping hypothesis* was proposed by Ellis and Lambon Ralph (2000) and further developed by J. Monaghan and Ellis (2002a) and Lambon Ralph and Ehsan (2006). This account is based on the behaviour of a series of simulations where a connectionist network was trained to associate pairs of input and output patterns gradually fed into training. The network performance resembled the AoA effect, and the best results were observed for early trained material and less accurate learning for patterns entered at later points. Ellis and Lambon Ralph (2000) observed that early entered patterns adjusted the weights of their connections to their advantage, providing the network a configuration favourable to their learning. Patterns introduced late did not have the same capacity for adjusting their weights and were, therefore, learned with less accuracy. Importantly, Ellis and Lambon Ralph asserted that the connections shaped by early regular or predictable input-to-output patterns would favour the learning of late-entered regular patterns. These cases of order of entry, or the AoA, would not affect performance because late material would exploit the connections created by the early learned material. However, when the mappings respond to the arbitrary connections' differences between early and late-entered items, this phenomenon is expected because early mappings cannot assist late learning. Using connectionist models, Zevin and Seidenberg (2002) reproduced these results and determined that a genuine AoA effect is observed when the mapping is arbitrary but suggested that AoA effects are simply cumulative frequency effects when the mapping is systematic and regular.

Monaghan and Ellis (2002a) studied how AoA affected reading aloud of English words with consistent or inconsistent spelling-to-sound relationships. They found independent effects of both AoA and consistency, but these effects were part of an interaction where AoA effects were larger for words with inconsistent spelling-to-sound mappings compared to those with consistent mappings. According to these results, the arbitrary mapping hypothesis predicts null or reduced AoA effects when naming words in languages with transparent orthographies, for example, Dutch, Spanish, Turkish, or Italian, because learning to translate letters into sounds in these languages is highly predictable. For instance, learning how the letters */p/, /e/, /n/,* and */a/* sound in Spanish allows the correct reading of words such as *pena* (sadness), *pan* (bread), *apnea* (apnoea), or *papá* (dad), irrespective of when these words entered the vocabulary of the individual. In fact, the literature review by Elsherif et al. (2023) suggests that the AoA effect in languages with opaque orthographies such as English is larger than languages with transparent orthographies.

By contrast, the arbitrary mapping hypothesis predicts substantial AoA effects in object naming because they rely on the arbitrary connections made between a concept and its name. Many studies have found support for the arbitrary mapping hypothesis in a variety of languages and tasks (Bakhtiar & Weekes, 2015; Boning et al., 2004; Havelka & Tomita, 2006; Izura & Ellis, 2004; Izura et al., 2011; Juhasz, 2005; Monaghan & Ellis 2002a, 2002b; Pérez, 2007; Ramanujan & Weekes, 2020). However, contrary to the predictions derived from this hypothesis, studies have reported robust AoA effects when naming words in transparent languages such as Spanish, Turkish, and Italian (Cuetos & Barbón, 2006; Davies et al., 2013; Raman, 2006; Wilson et al., 2012).

Role of phonology in the AoA effect

The *phonological completeness hypothesis* (Brown & Watson, 1987) is an early account of AoA abandoned in the 1990s that accounted for the AoA effects observed when naming words in transparent languages with ease. According to the phonological completeness hypothesis, early-acquired words are stored as whole units in the phonological output lexicon. As the child's vocabulary increases, the limited storage capacity of the system forces the new words to be stored in a fragmented manner; thus, the system saves space as the majority, if not all, the words in a given language can be generated through multiple combinations of a set of small units. This storage efficiency has, however, a processing cost for the late learned words because they must be assembled each time they are needed, and the direct access to the holistically represented early words endows them with a processing advantage. The phonological completeness hypothesis predicts AoA effects in tasks requiring the activation of the phonological representations. Indeed, AoA effects are found in tasks that undeniably activate the phonological system such as picture naming (e.g., Chalard & Bonin, 2006; Pérez, 2007) and word naming (Cortese & Khanna, 2007; Cortese et al., 2020). In addition, the effects of the AoA observed in the visual lexical decision task (e.g., Cortese et al., 2020; González-Nosti et al., 2014) were also explained according to the phonological completeness hypothesis because of the automatic access to phonology in this task (e.g., Carreiras et al., 2005; Conrad et al., 2009; Frost, 1998; Grainger & Ferrand, 1996; Lukatela et al., 1998; Perea & Carreiras, 1998).

J. Monaghan and Ellis (2002b) tested the phonological completeness hypothesis by using a phonological segmentation task where participants were asked to break down words according to three phonological criteria: at the initial consonant cluster, at the onset-rime level, and at the syllable level. They hypothesised that if early-acquired words are stored holistically, participants should show a processing cost when segmenting early acquired words and not when segmenting later acquired words.

Contrary to the predictions, the results showed faster segmentation times for early- compared with late-acquired words, and this result did not support the phonological completeness hypothesis. The findings in J. Monaghan and Ellis' (2002b) and the observations of AoA effects in tasks where phonological activation is not required, for example, discriminating between real and invented objects (Vitkovitch & Tyrell, 1995) or between celebrity and unfamiliar faces (Moore & Valentine, 1998), moved the support from the phonological completeness hypothesis to the semantic and/or the mapping hypotheses.

However, the phonological completeness hypothesis might have been rejected too soon without full consideration of the importance of phonology in the acquisition of vocabulary, particularly early vocabulary, or reflection on the extent to which the phonological representations of early- and late-acquired words vary as a result of vocabulary development. Thus, for example, studies have suggested that the holistic phonological representations formed while learning the first words are not permanently or uniquely stored as whole units. The *lexical restructuring hypothesis* by Metsala and Walley (1998) suggested that the initial holistic representation of early-acquired words changes with vocabulary growth and frequency of use and is stored in a fragmented manner. Importantly, the early holistic representations might not be completely erased (Jusczyk, 1986, 1993), early learned words might undergo a process of segmentation in the phonological system with time but might always maintain their original holistic form. Moreover, Jusczyk (1993) proposed that recognition might occur by activation of multiple stored traces generated by and available to a given word.

Thus, if we consider that first learned words are represented in, at least, two different formats (holistic and fragmented), the findings in J. Monaghan and Ellis (2002b) findings could be accounted for by a phonological hypothesis that embraces a dual representation for early learned words. The holistic trace of early-acquired words means rapid processing under normal circumstances but, because early learned words also go through a process of segmentation (they might even serve as templates for the whole segmentation process), the multiple activation of the whole unit and its segments might give them an advantage over late-acquired words in segmentation tasks.

We acknowledge that the phonological completeness hypothesis, or a version of it, cannot explain the AoA effects found in tasks that can be completed without phonology. For example, Perret et al. (2014), through ERP recordings, demonstrated that the locus of the AoA is phonological for spoken word production and orthographic for handwritten word production. However, most evidence shows that AoA effects are likely located in more than one specific linguistic structure (perceptual/orthographic, semantic and phonological) (e.g., Catling & Johnston, 2009; Cortese et al., 2020; see Elsherif et al., 2023 for a review). Therefore, as suggested, the mechanism(s) underlying the effect might apply to almost all loci of lexical processing (Johnston & Barry, 2006; Raman, 2006). In this study, we argue that one locus is the phonological system where the very first lexical learning occurs.

We assert a further hypothesis that also considers qualitative differences in the representation of early- and late-acquired words at the phonological level, *the sensorimotor integration hypothesis* (Hernández & Li, 2007). According to this account, a sensorimotor integration is the broad mechanism/s underlying the AoA effects observed in lexical processing (see Johnston & Barry, 2006; Juhasz, 2005), in the acquisition of a second language (Flege et al., 1995; MacKay & Flege, 2004), and in non-linguistic abilities such as stereoscopic depth perception and auditory spatial perception (Brainard & Knudsen, 1998; Fagiolini et al., 1994).

In relation to lexical processing, the *sensorimotor integration hypothesis* is partly based on Fiebach et al.'s (2003) findings. They recorded ERPs while participants performed a visual and an auditory lexical decision task. They found that visually presented early-acquired words activated the auditory cortex (i.e., the temporo-opercular region) more profusely than late-acquired words. Consequently, they suggested that early-acquired words are represented in the brain more strongly in their acoustic form (a sensory format) than late-acquired words (Fiebach et al., 2003; Hernandez & Li, 2007). They attributed the special role of the phonological codes when recognising early-acquired words to the vital function that auditory processing plays in the acquisition of the vocabulary during the first years of life:

> Words acquired early and later in life do not necessarily differ in length, frequency, or other relevant lexical variables. However, they do differ in the way they are learned. Early in life (i.e., until about 5 or 6 years of age) language is in general learned exclusively through the auditory modality. (Fiebach et al., 2003, p. 1635)

Phonological formal priming

A wealth of studies has shown that visual word recognition is influenced by phonology across all spelling systems (e.g., Frost, 1998; Leinenger, 2014). The conversion of printed letters of alphabetic orthographies (i.e., graphemes) into sounds (i.e., phonemes or syllables) occurs early in processing and is both fast and automatic (Brysbaert, 2001; Grainger & Ferrand, 1996). Robust facilitation effects have been observed when pseudohomophones (i.e., invented words that sound like real words such as*'crain'*) are used as primes for target words (e.g., '*crane*') in lexical decision tasks (Ferrand & Grainger, 1993; 1994; Frost, 1998; Lukatela et al., 1998). This priming effect observed for pseudohomophones (e.g., *'lais'* > *'lace'*) is generally larger than that found for primes similar to only the target in their orthography (e.g., *'laft'* > *'lace'*) (Grainger & Ferrand, 1994, 1996). Importantly, the phonological priming effect has been found when primes are presented briefly, that is, in the shorter range between 30–50 ms (Ferrand & Grainger, 1993; Lukatela et al., 1998; Perea & Rosa, 2002), indicating that assembled phonology becomes active very fast after the presentation of the prime. These findings have been interpreted as evidence of phonological mediation in visual word recognition and support a perspective of lexical access based on a parallel/distributed representation (i.e., orthographic and phonological sublexical codes that contribute simultaneously to lexical activation) (Ferrand & Grainger, 1993 1994, 1996; Frost et al., 2003; Grainger & Ferrand, 1994, 1996; Lukatela et at., 1998; Lukatela & Turvey, 2000; Ziegler et al., 2000).

In addition, studies have shown that the phonological mediation in visual word recognition varies with the orthographic depth of the orthography (Frost, 1998; Frost et al., 1987). According to the orthographic depth hypothesis (Frost et al., 1987), word recognition in transparent languages is more likely to be influenced by phonology than opaque languages.

In this study, we present an investigation of the phonological contribution to the AoA effect in the early stages of lexical access (well before semantic activation occurs) in orthographically transparent and opaque languages. To this end, we selected a formal priming paradigm embedded into a lexical decision task where the primes were pseudowords and the target words were early- or late-acquired. We aimed to test the predictions from the aforementioned hypotheses. The arbitrary mapping hypothesis (Ellis & Lambon Ralph, 2000) predicts no differential priming for early- and late learned words in languages with consistent letter-to-sound conversion rules such as Spanish but larger AoA effects in languages with inconsistent rules such as in English. The semantic hypothesis predicts that phonological priming in either language will not modulate the AoA effect because formal priming occurs in the very early stages of word recognition, well before semantic processing begins (see Perea & Rosa, 2002). By contrast, the phonological hypotheses (i.e., the phonological completeness and the lexical restructuring hypotheses) and the sensorimotor integration hypothesis predict AoA effects in any task where phonology is involved, regardless of language transparency.

The two experiments presented in this study followed a procedure similar to that adopted by Grainger and Ferrand (1996), that is, a visual lexical decision task combined with formal priming. In Experiment 1, we examined whether the AoA of target words might be affected by phonological and orthographic primes in Spanish. In Experiment 2, the same procedure was adopted to investigate phonological priming and the AoA effect in English.

Experiment 1

Experiment 1 explored the influence of AoA on early stages of visual word recognition in Spanish by examining the effects of AoA and formal priming (with short SOAs) in a lexical decision task. We adopted a similar procedure to that used by Grainger and Ferrand (1996), where phonological, orthographic, and unrelated primes were presented for 43 ms. Target words were all low frequency because AoA effects are usually larger when recognising low-frequency words (Alija & Cuetos, 2006; Bonin et al. 2001; Gerhand & Barry, 1999; González-Nosti et al., 2014; Stadthagen-Gonzalez et al., 2004; Wilson et al., 2013).

According to the arbitrary mapping hypothesis, neither orthographic nor phonological primes would modulate the AoA effect because the correspondences between orthography and phonology are regular in Spanish. The semantic hypothesis also predicts a lack of interaction between AoA and priming because the primes used should intervene in the very early stages of processing before any semantic consultation occurs. By contrast, the phonological hypotheses (phonological completeness and lexical restructuring) and the sensorimotor integration hypothesis expect an interaction between phonological priming and AoA regardless of language transparency or semantic influence. More specifically, considering that late-acquired words are represented in a segmented manner and early-acquired words in a complete mode, formal priming would only affect late-acquired words. However, when considering a dual representation (i.e., complete and segmented) of early-acquired words, formal priming would equally affect early- and late-acquired words.

Method

Participants

Fifty-four students (40 women) from the University of Murcia (Spain) participated in the experiment in exchange for credits, and their mean age was 23 years (SD = 4.7). All the participants provided informed consent, had normal or corrected-to-normal vision, and were Spanish native speakers.

Design and materials

Targets. Thirty experimental low-frequency words and 20 fillers were used (Table 1). Fifteen experimental words were classified as early-acquired and another 15 experimental words were classified as late-acquired, according to the objective-AoA values from Pérez and Navalón (2005). These scores were highly correlated with the AoA ratings by Alonso et al. (2015), $r(30) = .786$, $p < .001$. These two sets of words were matched (all $p > .1$) in the following variables: a) written word frequency from the LEXESP (Sebastián et al., 2000) and spoken word frequency from the ESPAL subtitle tokens database (Duchon et al., 2013); b) contextual diversity from the ESPAL movies database (Duchon et al., 2013); c) word length in letters, phonemes, and syllables; d) different indexes for orthographic neighbourhood from Pérez et al. (2003); and e) positional syllable-frequency of the first syllable from Sebastián et al. (2000). All words except one filler ('kilo') were object nouns; imageability and concreteness mean ratings (from Duchon et al., 2013) were not statistically different ($p > .1$). The scores for each word in each variable are presented in the Appendix A at https://osf.io/k9v83/. The filler words and experimental words had similar features, with no statistical differences between means across the aforementioned variables ($p > .1$).

Table 1
Characteristics of the word sets used in Experiment 1

	Experimental words			Filler words	
Variable	Early	Late	*p* value	Scores	*p* value
Objective AoA[a]	41.1 (27-53)	83.3 (56-143)	< .001	-	-
Subjective AoA[b]	4.0 (2.9-6.7)	5.6 (3.5-6.7)	.001	-	-
WF-LEXESP[c]	11.4 (1-29)	11.8 (0-34)	.934	14.1 (1-73)	.568
WF-ESPAL[c]	17.2 (2-70)	11.6 (0-39)	.387	14.9 (0-70)	.914
CD-ESPAL[d]	4.9 (1-14)	4.1 (0-14)	.649	5.4 (0-27)	.597
Imageability	6.2 (5.8-6.5) [3]	6.1 (5.6-6.5) [2]	.490	6.2 (4.6-6.9) [4]	.819
Concreteness	6.1 (4.9-6-6) [6]	6.1 (5.5-6.5) [6]	.921	6.0 (5.3-6.6) [4]	.534
N-Let	5.6 (4-8)	6.0 (4-8)	.365	5.9 (4-8)	.899
N-Syl	2.4 (2-3)	2.5 (2-3)	.481	2.7 (2-3)	.208
N-Phon	5.3 (3-8)	5.7 (4-8)	.337	5.8 (3-8)	.544
N	5.5 (0-19)	5.5 (0-20)	.977	6.2 (0-28)	.739
Nf	0.5 (0-3)	1.1 (0-8)	.310	1.0 (0-8)	.744
F-Syl[c]	7754 (103-26099)	9013 (60-26099)	.743	8577 (248-60016)	.959

Note. Mean (maximum–minimum values), [number of words with unknown ratings], WF-LEXESP: word frequency form Sebastián et al. (2000) database. WF-ESPAL: word frequency from Duchon et al. (2013) subtitle database. CD-ESPAL: contextual diversity from Duchon et al.. N-Let, number of letters. N-Syl, number of syllables. N-Phon, number of phonemes. N, number of neighbours from Pérez et al. (2003). Nf, number of neighbours with frequency higher than that of the target word from Pérez et al. F-Syl, positional syllable-frequency of the first syllable from Sebastian et al.
[a]In months. [b]In years (from 1 to 11). [c]Per Million. [d]Percentage of movies.

Fifty orthographically legal pseudowords were created to be included as targets in the lexical decision task and were statistically equivalent ($p > .1$) to the target words in terms of a) word length by letters (M = 5.6, range = 3-8), phonemes (M = 5.3, range = 2-8), and syllables (M = 2.4, range = 2-3); b) orthographic neighbourhood (M = 1.9, range = 0-10); and c) positional syllable-frequency of the first syllable (M = 7757.9, range = 7-60089). Additionally, target pseudowords and target words shared the same initial letter.

Primes. Following Grainger and Ferrand's (1996) procedure, we constructed three different types of phonotactically legal pseudoword primes for each experimental word: a) homophonic primes were pseudowords sharing 100% of phonemes and syllables in the same position with the target words (e.g., vúo-BÚHO (*owl*), both sound /ˈbu.o/); b) orthographically related primes were pseudowords sharing more letters than phonemes per position with the target words (e.g., guko-BÚHO, /ˈgu.ko/ and /ˈbu.o/, respectively); and c) unrelated primes were pseudowords that did not share any letters or phonemes per position with the target words (e.g., gife-BÚHO, /ˈxi.fe/ and /ˈbu.o/, respectively). Unrelated primes were incorporated as a control condition to compare the effects of homophonic and orthographic primes. The homophonic and orthographic primes were on average statistically different from each other in relation to the percentage of shared phonemes and syllables but not in terms of letters shared with the target words (Table 2). The homophonic primes had statistically more phonemes and syllables shared with the targets than the orthographic primes. Both types of primes shared similar percentages of letters with targets (i.e., it is virtually impossible to create pseudohomophones without orthographic overlapping in Spanish) but never the first letter. This was performed to avoid that possible effects of orthographic priming would be reduced to a mere first-letter effect (see Adelman, 2011 for review, and e.g., Aschenbrenner et al., 2017, for results on the prominent effect of the first letter in word recognition). No interactions were observed between the AoA manipulation of the target words and any of the former comparisons. Table 2 shows a summary of the characteristics of each type of prime.

Table 2
Mean percentage (and standard deviation) of shared units per position between primes and targets in Experiment 1

Type of prime	Letters	Phonemes	Syllables[a]
Phonologically related (pseudohomophones)	52 (.4)	100 (0)	100 (0)
Orthographically related	58 (.1)	20 (.2)	5 (.1)
Unrelated	0	0	0
p values (Phonological vs. orthographic primes t-test)	.466	$< .000$	$< .000$

[a]As a phonological unit

Three lists of prime-target pairs were created. The lists comprised the 30 target experimental words paired with phonological primes (n = 10), orthographic primes (n = 10), and unrelated primes (n = 10). Primes were not repeated within or across lists, and the target words were repeated across but not within lists. In addition, each list comprised 20 target filler words paired with 20 primes which varied across lists (these primes were selected from those used for the experimental primes to ensure that the same prime was not repeated within a list; Appendix A). The lists were then presented in a balanced manner across participants (i.e., 18 participants were randomly allocated per list).

Finally, 50 pseudowords were generated to act as primes of the pseudoword targets: 17 of homophonic with its targets, 17 were orthographically related to the target, and the remaining 16 were completely unrelated to their pseudoword targets. Thus, pseudoword targets (stimuli to reject as words in the lexical decision task) had similar priming conditions compared with the target words.

Procedure

We used the lexical decision task embedded into a masked priming paradigm similar to that implemented by Grainger and Ferrand (1996). The experiment was conducted in a quiet and light-controlled room. A computerised programme was designed using E-Prime (Schneider et al., 2002) to show the stimuli and collect the responses. The stimuli were presented in white ink over a black background (font Courier New, size 18 at an 800 x 600 screen configuration) and centred on a Philips-105E 15”screen at 70 Hz connected to a PC PIII-400MHz. Each trial started with a string of eight dashes (########) presented for a random duration of 800, 900, 1000, 1100, or 1200 ms to avoid potential strategic responses from participants predicting the moment when stimuli would appear (see Soetens, 1998). Inter-trial duration variations do not interact with word and pseudowords response times (Perea & Carreiras, 2003, Experiment 1).

Participants were instructed to look exactly at the third dash from the left of the dash string, which was marked in this manner, $\bar{\#}$. Immediately after that and in the same position where the dashes were on the screen, a prime was presented in lowercase for 43 ms (i.e., for three screen cycles at 70 Hz). The target remained on the screen until the participant made a response or after 1500 ms if no response was detected. Next, a blank screen was presented for 600 ms as an inter-trial interval. Right-handed participants had to press the ‘M’ key for words and ‘Z’ for pseudowords, and left-handed participants performed the inverse. Participants were encouraged to respond as accurately and quickly as possible and were not informed of the presence of primes. The order of presentation was semi-randomised to avoid the same type of target (word or pseudoword) appearing more than four times consecutively. This measure was taken to avoid the cumulative effect on response times for consecutive trials that require the same type of response (i.e., response times are shorter for a word if the previous stimulus was also a word with respect it was a pseudoword; e.g., Lima & Huntsman, 1997).

Before the start of the experiment, participants had 42 trials for practice (21 words and 21 pseudowords with the same characteristics as in the experimental block), with feedback in terms of their accuracy and time of response. Six transition-trials (three words and three pseudowords) without feedback were presented between the practice set and the experimental set. The experimental session took approximately 15 min.

Statistical analysis

We used a lineal regression model, LMM (function *lmer*, belonging to the *lme4* package version 1.1-34; Bates et al., 2015), in R version 4.3.1 (R core team, 2023), via RStudio version 2023.06.2 (Rstudio Team, 2023).

Results

All participants performed above chance level accuracy, as predicted by the binomial distribution for 100 trials at $p <$ .001 (The lowest mean accuracy rate was 78%, and the highest was 100%), thus all of them were included for analysis. As there were very few error responses (6,5%), the data analysis focused on the effects of word latencies, considering only those manipulated by AoA. A file with the dataset is available as supplementary material to this article at https://osf.io/k9v83/.

We examined the latencies of correct responses to the target words only (i.e., 1515 single observations, M = 658 ms, SD = 152, min = 318 ms, max = 1470 ms, skewness = 1.283) fitting a LMM to estimate effects of prime type (homophonic, orthographic, and unrelated) and AoA of target words (early and late) and their interaction. Following a common practice to reduce the typically positive skewness of recognition latencies, we transformed each reaction time (RT) to its reciprocal (i.e., 1/RT), resulting a skewness = 0.215 after transformation. We selected a random-effects structure according to our experimental design and to reduce Type-I error (Barr et al., 2013) by including the between-participants and between-items effects and the slopes of variables of interest (i.e., the same as fixed effects) within participants. The fixed-effect structure was composed by the factors 'prime type', 'target AoA', and their interaction. The model converged with no warnings (the *bobyqa* optimizer of convergence was used) and the model equation was 1/RT ~ PrimeType*TargetAoA + (1 + PrimeType*TargetAoA | Participant) + (1 | Target).Then, based on that model, the estimated marginal means (EMMs) were contrasted by priming, AoA, and their interaction (function *emmeans*, *specs* = pairwise, *adjust* = "bonferroni", belonging to the *emmens* package, version 1.8; Lenth, 2023). See Figure 1 for untransformed mean RT by experimental conditions. The main effect of AoA was significant, with faster recognition times for early-acquired words than for late-acquired words (estimate = 0.000104, t(28.7) = 2.524, p = .017; untransformed mean-RT for early-acquired words = 613 ms and for late-acquired words = 654 ms). The effect of phonological priming was also significant, with the words primed by homophonic pseudowords being recognised faster than those primed by orthographic primes (estimate = 0.0000456, t(51.5) = 2.746, p = .025; untransformed mean-RT for phonological-primed words = 621 ms and for orthographic-primed words = 641 ms) and by unrelated pseudowords (estimate = 0.0000447, t(51.5) = 2.712, p = .027; untransformed mean-RT = 641 ms). The target words primed by orthographic primes were recognized as fast as when they follow the unrelated primes. Importantly, when the priming effects were contrasted separately by AoA conditions, the phonological priming effect was only significant for the late-acquired words in the contrasts phonological vs. orthographic primes (estimate = 0.0000612, t(51.5) = 2.541, p = .039; untransformed mean RT for phonological-primed words = 637 ms and for orthographic-primed words = 662 ms) and phonological vs. unrelated primes (estimate = 0.0000721, t(50.9) = 3.225, p = .007; untransformed mean RT for unrelated-primed words = 667) (see Figure 1). There were no significant effects of priming for the early-acquired words (untransformed mean-RT for phonological-primed words = 610 ms, for orthographic-primed words = 621 ms, and for unrelated-primed words = 613).

Discussion

The results of Experiment 1 show clear main effect of AoA and phonological priming RT. No orthographic priming was found. Notably, an interaction between AoA and phonological priming was also found on RT, with the phonological priming effect appearing only in the late-acquired words. Because the SOA was short (43 ms), priming effects must be considered purely formal, that is, free of semantic influence (e.g., Perea & Rosa, 2002).

Therefore, the observed interaction between AoA and phonological priming is an indication that AoA is involved in the early stages of visual word recognition. This is the first time that this phenomenon has been reported. The nature of phonological primes (i.e., pseudohomophones of the target words) indicates that the influence of AoA might be at a phonological level, although a partial influence of orthography cannot be fully discarded because primes and targets shared overall half (52%) of the letters at the same position. However, we assert that this orthographic influence, if any, seems irrelevant because those primes sharing 58% of letters and 20% of phonemes in the same position did not cause a significant effect on lexical decision times. Another indication that the phonological priming was not orthographic is that we used low written-frequency words as targets and assumed that they were weakly represented in the orthographic lexicon and not easily primed by orthographically related inputs (e.g., Chateau & Jared, 2000).

The phonological priming effect found in this study has never been reported in Spanish. Carreiras and Perea (2002) found formal priming effects in Spanish by using pseudowords as primes that shared the first full syllable, in phonology and orthography, with word targets and (SOA = 64 ms). Pollatsek et al. (2005) found similar effects in Spanish through a manipulation of prime-target pairs sharing the first letter and sound (conal-CANAL, /koˈnal/-/kaˈnal/), but a diminished priming effect when they share only the first letter but not the first sound (cinal-CANAL, /θiˈnal/-/kaˈnal/). This advantage for the first phoneme appeared with an SOA of 66 ms but not of 50 ms. In our Experiment 1, the phonological priming effect was obtained with primes sharing phonology 100% but not the first letter. Similar results have been shown in other studies using the same experimental paradigm in Dutch (Brysbaert, 2001; Experiment 2), French (Grainger & Ferrand, 1996; Experiment 1), and English (Perfetti & Bell, 1991; Experiment 3). The facilitatory effect of phonological formal priming on target words caused by homophonic pseudowords can be explained through the sublexical pathways in the interactive activation models of written word recognition (e.g., Coltheart et al. 2001; Conrad et al., 2009; Grainger et al., 2003; see Ferrand & Grainger, 1994; Grainger, 1992; see also the general discussion).

The critical and novel finding in this experiment is the interaction of AoA and formal phonological priming. Results show that the phonological priming effect (25 ms) appears only when recognising late-acquired words. No priming effect was observed in the recognition of early learned words (see Figure 1). In other words, the interaction between factors is because of the recognition of late-acquired words enjoying a greater facilitation from the phonological priming than the early-acquired words. Additionally, recognition times under orthographic and unrelated priming conditions are virtually identical.

Overall, the results suggest an action locus of AoA at the early phonological stages of visual word recognition: Specifically, in letter-to-sound conversion processes and/or at the access to the phonological lexicon. The semantic hypothesis cannot explain these findings because involvement of the semantic representations was not observed. The mapping hypothesis predicts AoA effects when the orthography-to-phonology conversion is required even if no semantic representations are involved (see P. Monaghan and Ellis, 2010). This case is not the case for Spanish, in which orthography-to-phonology conversion rules are consistent. Thus, the most currently accepted hypotheses for AoA effects cannot explain the effect encountered in this study. We provide other possible explanations in the general discussion.

Experiment 2

In Experiment 2, we aimed to replicate Experiment 1 in a non-transparent language: We explored the influence of AoA in early stages of visual word recognition in English. The lexical decision and the formal priming paradigm were used in exactly the same fashion as in Experiment 1.

In this investigation of the phonological mediation of the AoA effect in English, we used a language whose letter(s) to sounds correspondences are not transparent, which allowed a more flexible and varied generation of homophonic primes. In English, nearly every sound has more than one spelling format (e.g., the long vowel /ɜː/, can be spelled as *'u,' 'ea,'* and *'i'* as in *'nurse,' 'heard,'* and *'third'*). In Spanish, however, a very few phonemes can be spelled in more than one manner. The hypotheses reviewed in this study made the same predictions as in Experiment 1, except for the arbitrary mapping hypothesis. In Experiment 2, the phonological priming should modulate the AoA effect because the letter(s) to sound correspondences are irregular. The phonological completeness hypothesis and the sensorimotor integration hypothesis should also predict an interaction between phonological priming and the AoA effect, but the semantic hypothesis will not predict such interaction.

Method

Participants

Forty under- and post-graduates (24 women) from Swansea University (in United Kingdom) participated in the experiment. They provided informed consent and received a compensation of 3 pounds for participation. The mean age was 27.7 years (SD = 7.9). All participants had normal or corrected vision and were native speakers of English.

Material

Thirty-six experimental low-frequency words (Table 3): 18 were classified as early-acquired and the other 18 as late-acquired, according to the objective AoA values from Morrison et al. (1997) and Kuperman et al. (2012). These two set of words were matched (all $p > .1$) in the following variables: a) written word frequency from CELEX (Baayen et al., 1993) and the English Lexicon Project subtitle database (Balota et al., 2007), b) contextual diversity from the English Lexicon Project (Balota et al., 2007), c) word length in letters, phonemes, and syllables, d) some indexes for orthographic neighbourhood from N-Watch (Davis, 2005), and e) bigram type and token frequencies from N-Watch (Davis). Although all words were object nouns, imageability mean ratings were statistically different depending on the norms we consulted. No differences were observed between early- and late-acquired words in concreteness (Table 3). The scores for each word in each variable are presented in Appendix B at https://osf.io/k9v83/.

Thirty-six orthographically legal pseudowords were created by changing one or two letters from the real words (never the first letter) and were used as target pseudowords (stimuli to reject as words in the lexical decision task). These words were statistically equivalent to the target words in word length (by letters, M = 5.9, range = 4-9) and orthographic neighbourhood (M = 1.8, range = 0-7).

Primes. For Experiment 2, we generated only one type of pseudoword prime for each experimental word. Thus, the 36 pseudoword primes were homophones of the target words. However, the presentation format of the pseudowords primes was devised to suit two different conditions: 1) priming its homophonic target word (e.g., kandel-CANDLE, both sounding /ˈkændəl/); 2) priming another word with which it did not share any letter or phoneme in the same position (e.g., jeraf-CANDLE, sounding /dʒɪˈrɑːf/-/ˈkændəl/). In the homophonic condition, the primes shared an average of 28% of letters (but never the first letter), 100% of phonemes, and 100% of syllables (as phonological units) per position with the target words. In the unrelated condition, the primes shared 0% letters, phonemes, or syllables with the target words. To avoid the repetition of the primes, we built two lists (1 and 2) with 36 prime-target pairs each. In list 1, half of the target words were primed by their associated homophonic primes and half by the nonassociated homophonic primes. This situation was reversed for list 2. Both lists were counter-balanced across participants, with a total of 20 randomly-assigned participants on each list. Thus, each pseudoword prime worked as ahomophonic prime and unrelated prime (i.e., control condition). Appendix B provides additional details.

Table 3
Characteristics of the word sets used in Experiment 2.

	Experimental words		
Variable	Early	Late	*p* value
AoA-MCE[a]	36.6 (23-50)	95.9 (56-140)	< .001
AoA-KSB[b]	5.0 (2.7-8.1)	7.0 (5.1-10.8)	< .001
WF-CELEX[c]	6.7 (1-12)	4.8 (0-14)	.160
WF-ELP[c]	8.7 (1-22)	5.7 (0-19)	.135
CD-ELP	3 (0-6)	2.1 (0-8)	.198
IMG-MCE[b]	6.3 (5.6-6.7)	5.9 (5.2-6.5)	< .001
IMG-MRC[c]	597 (574-617) [4]	586 (536-619) [9]	.289
CON-MRC[c]	602 (560-628) [4]	580 (433-616) [9]	.277
CON-BWK[e]	4.9 (4.4-5.0)	4.7(3.3-5.0)	.168
N-Let	5.7 (3-8)	5.7 (4-8)	.905
N-Syl	1.7 (1-3)	1.9 (1-3)	.394
N-Phon	4.6 (3-7)	4.7 (3-6)	.876
N	2.9 (0-8)	1.6 (0-10)	.163
NF+	1.4 (0-5)	.8 (0-5)	.281
Bigram-Token[c]	464 (44-1760)	470 (112-1290)	.965
Bigram-Type	27 (3-67)	32 (12-74)	.350

Note. Mean for each word set, range between parentheses, number of words with unknown ratings between brackets. AoA-MCE, ratings from Morrison et al. (1997), AoA-KSB, ratings from Kuperman et al. (2012). WF-CELEX, word frequency form CELEX (Baayen et al., 1993) database. WF-ELP, word frequency from English Lexicon Project, subtitle database (Balota et al., 2007). CD-ELP, contextual diversity from English Lexicon Project (Balota et al., 2007). IMG-MCE, imageability from Morrison et al. (1997). IMG-MRC, imageability from the Medical Research Council database (Wilson, 1988). CON-MRC, concreteness from the MRC database (Wilson, 1988). CON-BWK, concreteness from Brysbaert et al. (2014). N-Let, number of letters. N-Syl, number of syllables. N-Phon, number of phonemes. N, number of neighbours from N-Wach (Davis, 2005). Nf, number of neighbours with frequency higher than that of the target word, from N-Watch (Davis, 2005).
[a]In months. [b]Scale from 1-to-7. [c]Per Million. [d]Scale from 100-to-700. [e]Scale from 1-to-5

In addition, we created 36 pseudowords to use as primes of the same number of pseudoword targets; 18 were homophonic of its targets, and the remainder were completely unrelated to its pseudoword targets. Thus, pseudoword targets had similar prime conditions compared with the target words.

Procedure

The laboratory conditions and computer specifications were the same as in Experiment 1, except that we used a Philips-105E 17"screen connected to a PC (Intel D850GB). The sequence and duration of events were exactly the same as in Experiment 1. Before the experimental set, participants were shown 20 practice trials (ten words and ten pseudowords with the same characteristics as those of the experimental block) with feedback in terms of their accuracy and time of response. Four transition-trials (two words and two pseudowords) without feedback were presented between the practice set and the experimental set. The duration of the whole experimental session was approximately 10 min.

Statistical analysis

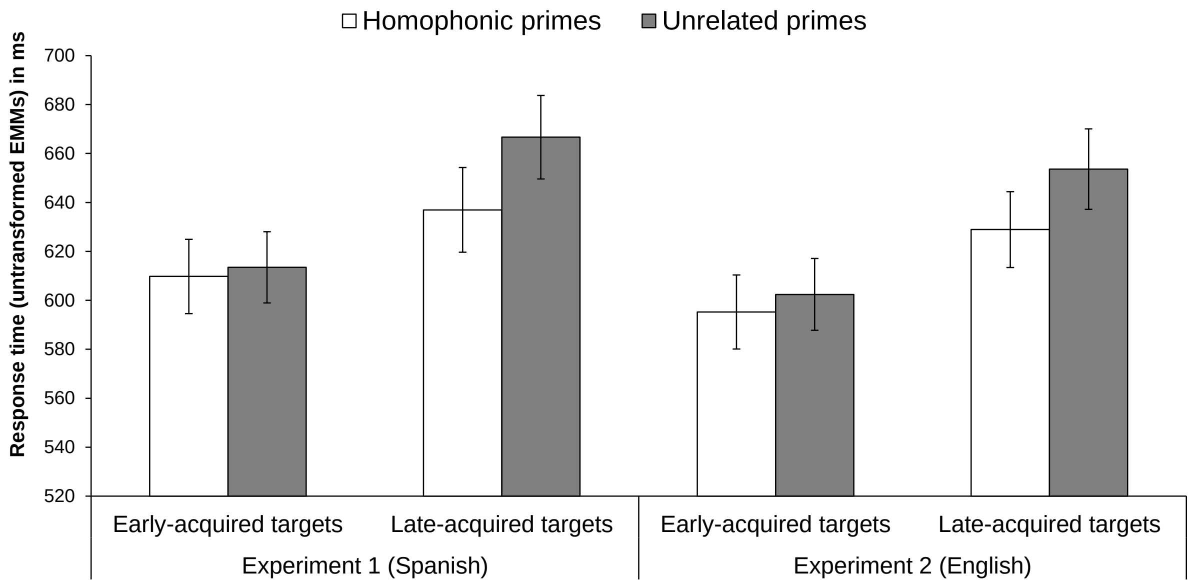
We used the same LMM technique described in Experiment 1.

Results

One participant was eliminated because he informed us that he had confused the response keys for some time during the experiment. The remainder of the participants performed at an accuracy rate significantly higher than chance, as predicted by the binomial distribution for 64 trials at $p < .001$ (min = 86%, max = 100%). However, a further three participants were eliminated from analyses because they had extremely high mean RTs (two standard deviations above the overall mean). Thus, data form 36 participants (18 per list) were included in the following LMM analysis. Due to the very few error responses (6,1%), the data analysis focused on the effects of word latencies, considering only those manipulated by AoA. A file with the dataset is available as supplementary material to this article at https://osf.io/k9v83/.
As in Experiment 1, we first obtained a LMM of the latencies to correct responses (i.e., 1354 single observations, M = 645 ms, SD = 152, min = 372 ms, max = 1488 ms, skewness = 1.753) to estimate effects of prime type (homophonic and

unrelated) and AoA of target words (early and late) and their interaction, and then we calculated and contrasted the EMMs by priming, AoA, and their interaction. We used the same functions, software, and RT transformation described in Experiment 1 (transformed 1/RT skewness = 0.215). The random-effects structure of the regression model comprised the between-participants and between-items effects and the slopes of variables of interest (i.e., the same as fixed effects) within participants. The fixed-effect structure was composed by the factors 'prime type', 'target AoA', and their interaction. The model converged with no warnings and the model equation was 1/RT ~ PrimeType*TargetAoA + (1 + PrimeType*TargetAoA | Participant) + (1 | Target). Contrast of EMMs from the model showed a main effect of AoA, with faster recognition times for early-acquired words than for late-acquired words (estimate = 0.000112, $t(35.9)$ = 3.270, p = .002; untransformed mean-RT for early-acquired words = 599 ms and for late-acquired words = 641 ms). The effect of phonological priming was also significant, with the words primed by homophonic pseudowords being recognised faster than those primed by unrelated pseudowords (estimate = 0.000037, $t(38)$ = 2.483, p = .018; untransformed mean-RT for phonological-primed words = 613 ms and for unrelated-primed words = 625 ms). When the priming effect were contrasted separately by AoA conditions, it was only significant for the late-acquired words (estimate = 0.0000502, $t(38)$ = 2.060, p = .046; untransformed mean RT for phonological-primed words = 629 ms and for unrelated-primed words = 654) (see Figure 1). There was no significant effect of priming for the early-acquired words (untransformed mean-RT for phonological-primed words = 595 and for unrelated-primed words = 602).

Figure 1
Phonological priming by AoA in Experiments 1 and 2.



Note: error bars = standard error of the untransformed EMMs.

Discussion

The results of Experiment 2 are very similar to those of Experiment 1. Main AoA and phonological priming effects were found on RT. The interaction between AoA and phonological priming on RT was also significant in Experiment 2 and strengthens the idea that the AoA of words affects the early stages of visual word recognition. The phonological primes of Experiment 2 (i.e., pseudohomophones of target words) shared only 28% of letters per position with the targets, which is almost half less than the phonological primes in Experiment 1. Thus, we can assume that the priming effect found in Experiment 2 is of a purer phonological nature.

Critically, this AoA effect observed in the early stages of word recognition (i.e., letter-to-sound-conversion process) was predicted by the arbitrary mapping hypothesis because English has a high degree of unpredictability between orthographic-to-phonological representations; however, other hypotheses can explain the results (see the general discussion).

General discussion

The results of both experiments show clear main effects of AoA and phonological priming on recognition times. No orthographic priming was found for target words in Spanish. Critically, the interaction between AoA and phonological priming, wherein the priming effect exclusively acted on late-acquired words, was found both in Spanish and English words.

Current interactive activation models of written word recognition (e.g., Coltheart et al. 2001; Conrad et al., 2009; Grainger et al., 2003; see also Ferrand & Grainger, 1994; Grainger, 1992) would account for the phonological formal priming effects observed in both experiments. The models assume that the activation triggered by the visual features of the primes activates their letters and/or grapheme units, which activate the corresponding phonemes through grapheme-to-phoneme conversion rules. Phoneme units would then directly activate the phonological form of words, although some models also include a syllabic parser between phonemes and words (i.e., Conrad et al., 2009). Syllable plays a critical role in word recognition in syllabic languages such as Spanish (e.g. Perea & Carreiras, 1998). Finally, words activated in the phonological lexicon activate the corresponding orthographic words. The greater the degree of phonological resemblance between the prime and the target, the greater and more specific the activation that reaches the target representation at the orthographic lexicon, and consequently, the faster it will reach the recognition level (see Lukatela et al., 2001, for phonological priming effects with phonological neighbour primes).

Thus, words in the orthographic lexicon receive more activation from homophonic primes than from the orthographic or unrelated primes; in this case, a direct activation from the letters shared between the prime and target and an indirect or backward activation from the phonological lexicon. However, the orthographic activation alone was not very effective, probably because all targets were low written-frequency words, which might be weakly represented in the orthographic lexicon. As a matter of fact, there was no orthographic priming effect. Overall, the phonological priming effect found in this study fits the standard explanation provided by the interactive models or word recognition of such an effect (see Carreiras & Perea, 2002, for similar results).

Notably, a phonological priming effect that facilitated only the recognition of late-acquired words was found. Overall, we posit that the interaction between AoA and phonological priming observed in this study is genuine and shows an involvement of the AoA effect at the early and phonological stages of visual word recognition, and likely in the letter-to-sound conversion processes and/or when accessing the phonological lexicon. This novel effect cannot be explained by the semantic hypothesis (e.g., Ghyselinck et al., 2004) because no involvement of semantic representations was observed; the SOA (43 ms) was too short to suppose a semantic influence within the priming effects reported in this study. The arbitrary mapping hypothesis predicts AoA effects in the absence of semantic consultation but only in the presence of inconsistent orthography-to-phonology (e.g., Lambon Ralph & Ehsan, 2006; P. Monaghan and Ellis, 2010), such as in English. However, Spanish has consistent letter-to-sound correspondences; thus, the effect found in Experiment 1 cannot be accounted for by applying this theory either. This result suggests that other mechanisms, different to those proposed by the arbitrary mapping hypothesis (Ellis & Lambon Ralph, 2000) or the semantic hypothesis, might be acting on word learning to account for this AoA effect in the early stages of visual word recognition.

Although this explanation is somewhat speculative, a possible explanation for the results found in this study is that the nature of the early- and late-acquired word representations in the phonological lexicon are qualitatively different, as stated by the phonological completeness hypothesis (Brown & Watson, 1987; see also Metsala & Walley, 1998). The early words would have a more complete (global) representation, and later words would be stored in a more segmented manner. If this assertion were true, under the aforementioned interactive models of word recognition, the phonological sublexical codes activated by the primes (i.e., phoneme, or syllable, or both) would facilitate late-acquired words' activation more than early-acquired words because of their segmented nature, which is precisely the effect observed in our experiment; however, this would not be sufficient to explain the main advantage of early- versus late-acquired words. This advantage could come from having complete representations in the phonological lexicon, which are more strongly and directly associated with the representations in the orthographic lexicon. Thus, forward and backward activations occur between the orthographic and the phonological lexicons, strengthening the word candidate in the orthographic lexicon.

An alternative explanation might be that the early-acquired words have a dual representation: complete because they have been incorporated early in the system and fragmented as a consequence of the transformations that the system undergoes for different reasons (Fowler, 1991). This hypothesis of dual representation was suggested by Jusczyk (1986) for the phonological output lexicon. Following this rationale, those words with few neighbours and low occurrence in the language, like the items used in this experiment, would preserve a complete or very little deteriorated global form until adulthood. During the acquisition of reading, these global representations would be associated with their corresponding orthographic forms by creating a direct and strong link between the orthographic and phonological lexicons. Additionally, sublexical units as phonemes and syllables are used to access words through orthography-to-phonology conversion. Thus, one possibility is that early-acquired words—mainly those that are infrequent and with few neighbours—are more directly accessed, perhaps from a type of 'archaic' representation, and the late-acquired words are accessed from sublexical units. This possibility would explain why the early-acquired words were not affected by the sublexical primes in the experiments in this study. However, the dual representation hypothesis would also predict a phonological priming effect for early-acquired words.

Although this study does not allow us to make contrasts among the phonological hypotheses (i.e., the phonological completeness and the lexical restructuring hypotheses), this study demonstrates that the most accepted explanations for the AoA effect—the arbitrary mapping hypothesis and the semantic hypothesis—are insufficient to explain all phenomena associated with AoA. In fact, recent evidence suggests a perceptual nature of AoA effects. Catling et al. (2021) employed the Recognition without Identification (RWI) paradigm, where individuals retain the ability to recognize a situation as familiar but struggle to recall specific details of the memory. This task is believed to reflect early perceptual processing stages. Catling et al. found that the interaction between RWI and AoA was evident only for pictorial stimuli, not for word stimuli, indicating that the AoA effect arises from perceptual rather than semantic processes. Additional evidence supports the notion that AoA may occur before semantic processing. Catling and Elsherif (2020) employed various methods, including picture-word verification, word-picture verification, spoken picture naming, spoken word naming, written picture naming, and written word naming, along with pictorial and word stimuli, to indirectly assess the presence of the AoA effect in representational links. They observed the AoA effect across all tasks. However, in word-picture verification, Catling and Elsherif observed a larger AoA effect in verification responses compared to falsification responses. Previous research (e.g., Bonin et al., 2006; Stadthagen-Gonzalez et al., 2009) suggests that falsification responses tap into early stages before semantic processes, while verification involves both perceptual and semantic processes. This implies that the AoA effect may originate at the perceptual rather than semantic level. We suggest that further research is required to contrast the possible effects of AoA independent from the neural plasticity of the learning network (which we do not deny) but associated with the different nature of information features stored along life or in the first stages of life. This suggestion has also been proposed by the defenders of embodied cognition science (Clark, 2006; see also Hernández & Li, 2007) for the sensorimotor integration hypothesis of AoA.

Complementary information

Ethics statement.- This research was approved by the Department of Psychology Ethics Committee at Swansea University and by the University of Murcia's Research Ethics Commission.

Materials and data accessibility statement.- Two appendixes (in PDF format) with detailed information of the stimuli used in the experiments 1 and 2 and two files (in spreadsheet format .xlsx) with the dataset at trial-level employed in the LMM analyses in both experiments can be found as supplementary materials to this article at https://osf.io/k9v83/.

Funding.- This work was supported by the public resources available to University of Murcia and Swansea University.

Conflict of interests.- The authors declare that they have no conflicts of interest.

References

Adelman, J. S. (2011). Letters in time and retinotopic space. *Psychological Review, 118* (4), 570-582. https://doi.org/10.1037/a0024811

Adorni, R., Manfredi, M., & Proverbio, A. M. (2013). Since when or how often? Dissociating the roles of age of acquisition (AoA) and lexical frequency in early visual word processing. *Brain and Language*, *124*(1), 132-141. Retrieved from https://doi.org/10.1016/j.bandl.2012.11.005

Alija, M., & Cuetos, F. (2006). Efecto de las variables léxico-semánticas en el reconocimiento visual de palabras [Effect of lexical-semantic variables on visual word recognition]. *Psicothema, 18*(3), 485–491 https://www.redalyc.org/articulo.oa?id=72718324

Aschenbrenner, A. J., Balota, D. A., Weigand, A. J., Scaltritti, M., & Besner, D. (2017). The first letter position effect in visual word recognition: The role of spatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 43*(4), 700-718. https://doi.org/10.1037/xhp0000342

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*(4), 390–412. https://doi.org/10.1016/j.jml.2007.12.005

Baayen, R. H., Piepenbrock, R., & van Rijn, H. (1993). *The CELEX lexical database*. Philadelphia, PA, USA: Linguistic Data Consortium, University of Pennsylvania.

Bakhtiar, M., & Weekes, B. (2015). Lexico-semantic effects on word naming in Persian: Does age of acquisition have an effect?. *Memory & Cognition, 43*(2), 298-313.

Balota, D. A., Yap, M. J., Hutchison, K. A., Cortese, M. J., Kessler, B., Loftis, B., …Treiman, R. (2007). The English lexicon project. *Behavior Research Methods, 39*(3), 445-459. https://doi.org/10.3758/BF03193014

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*(3). https://doi.org/10.1016/j.jml.2012.11.001

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software, 67*(1), 1-48. http://dx.doi.org/10.18637/jss.v067.i01

Bonin, P., Barry, C., Méot, A., & Chalard, M. (2004). The influence of age of acquisition in word reading and other tasks: A never ending story?. *Journal of Memory and language, 50*(4), 456-476. https://doi.org/10.1016/j.jml.2004.02.001

Bonin, P., Chalard, M., Méot, A., & Barry, C. (2006). Are age-of-acquisition effects on object naming due simply to differences in object recognition? CommentsonLevelt(2002).Memory & Cognition, 34(5), 11721182. https://doi.org/10.3758/BF03193263

Bonin, P., Chalard, M., Méot, A., & Fayol, M. (2001). Age-of-acquisition and word frequency in the lexical decision task: Further evidence from the French language. Cahiers de Psychologie Cognitive/Current Psychology of Cognition, 20(6), 401-443.

Brainard, M. S., & Knudsen, E. (1998). Sensitive periods for visual calibration of the auditory space map in the barn owl optic tectum. *Journal of Neuroscience, 18*(10), 3929–3942. https://doi.org/10.1523/JNEUROSCI.18-10-03929.1998

Brown, G. D. A., & Watson, F. L. (1987). First in, first out: Word learning age and spoken word frequency as predictors of word familiarity and word naming latency. *Memory & Cognition, 15*(3), 208–216. https://doi.org/10.3758/BF03197718

Brysbaert, M. (2001). Prelexical phonological coding of visual words in Dutch: Automatic after all. *Memory & Cognition, 29*(5), 765-773. https://doi.org/10.3758/BF03200479

Brysbaert, M. (2017). Age of acquisition ratings score better on criterion validity than frequency trajectory or ratings 'corrected' for frequency. *Quarterly Journal of Experimental Psychology, 70*(7), 1129–1139. https://doi.org/10.1080/17470218.2016.1172097

Brysbaert, M., Van Wijnendaele, I., & De Deyne, S. (2000). Age-of-acquisition effects in semantic processing tasks. *Acta Psychologica, 104*(2), 215-226. https://doi.org/10.1016/S0001-6918(00)00021-4

Brysbaert, M., Warriner, A. B., & Kuperman, V. (2014). Concreteness ratings for 40 thousand generally known English word lemmas. *Behavior Research Methods, 46*(3), 904-911. https://doi.org/10.3758/s13428-013-0403-5

Carreiras, M. & Perea, M. (2002). Masked priming effects with syllabic neighbors in a lexical decision task. *Journal of Experimental Psychology: Human Perception and Performance, 28*(5), 1228-1242. https://doi.org/10.1037/0096-1523.28.5.1228

Carreiras, M., Ferrand, L., Grainger, J., & Perea, M. (2005). Sequential effects of phonological priming in visual word recognition. *Psychological Science, 16*(8), 585-589. https://doi.org/10.1111/j.1467-9280.2005.01579.x

Catling, J. C., & Elsherif, M. M. (2020). The hunt for the age of acquisition effect: It's in the links!. *Acta Psychologica, 209*, 103138. https://doi.org/10.1016/j.actpsy.2020.103138

Catling, J. C., & Johnston, R. A. (2009). The varying effects of age of acquisition. Quarterly Journal of Experimental Psychology: *Human Experimental Psychology, 62*(1), 50–62. https://doi.org/10.1080/17470210701814352

Catling, J. C., Pymont, C., Johnston, R. A., Elsherif, M. M., Clark, R., & Kendall, E. (2021). Age of acquisition effects in recognition without identification tasks. *Memory, 29*(5), 662–674. https://doi.org/10.1080/09658211.2021.1931695

Chalard, M., & Bonin, P. (2006). Age-of-acquisition effects in picture naming: Are they structural and/or semantic in nature? *Visual Cognition, 13*(7-8), 864-883. https://doi.org/10.1080/13506280544000084

Chateau, D., & Jared, D. (2000). Exposure to print and word recognition processes. *Memory & Cognition, 28*(1), 143-153. https://doi.org/10.3758/BF03211582

Clark, A. (2006). Language, embodiment, and the cognitive niche. *Trends in cognitive sciences, 10*(8), 370-374. https://doi.org/10.1016/j.tics.2006.06.012

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: a dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*(1), 204-256. https://doi.org/10.1037//0033-295X.108.1.204

Conrad, M., Carreiras, M., Tamm, S., & Jacobs, A. M. (2009). Syllables and bigrams: Orthographic redundancy and syllabic units affect visual word recognition at different processing levels. *Journal of Experimental Psychology: Human Perception and Performance, 35*(2), 461. https://doi.org/10.1037/a0013480

Cortese, M. J., & Khanna, M. M. (2007). Age of acquisition predicts naming and lexical-decision performance above and beyond 22 other predictor variables: An analysis of 2,342 words. *The Quarterly Journal of Experimental Psychology, 60*(8), 1072-1082. https://doi.org/10.1080/17470210701315467

Cortese, M. J., Toppi, S., Khanna, M. M., & Santo, J. B. (2020). AoA effects in reading aloud and lexical decision: Locating the (semantic) locus in terms of the number of backward semantic associations. Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 73(11), 2036–2044. https://doi.org/10.1177/1747021820940302

Cuetos, F., & Barbón, A. (2006). Word naming in Spanish. *The European Journal of Cognitive Psychology, 18*(3), 415–436. https://doi.org/10.1080/13594320500165896

Davies, R., Barbón, A., & Cuetos, F. (2013). Lexical and semantic age-of-acquisition effects on word naming in Spanish. *Memory & Cognition, 41,* 297-311. https://doi.org/10.3758/s13421-012-0263-8

Davis, C. J. (2005). N-Watch: A program for deriving neighborhood size and other psycholinguistic statistics. *Behavior Research Methods, 37*(1), 65-70. https://doi.org/10.3758/BF03206399

Dent, K., Catling, J. C., & Johnston, R. A. (2007). Age of acquisition affects object recognition: Evidence from visual duration thresholds. *Acta Psychologica, 125*(3), 301-318. https://doi.org/10.1016/j.actpsy.2006.08.004

Duchon, A., Perea, M., Sebastián-Gallés, N., Martí, A., Carreiras, M. (2013). EsPal: One-stop Shopping for Spanish Word Properties. *Behavior Research Methods, 45*(4), 1246-1258. https://doi.org/10.3758/s13428-013-0326-1

Ellis, A. W., & Lambon Ralph, M. (2000). Age of acquisition effects in adult lexical processing reflect loss of plasticity in maturing systems: Insights from connectionist networks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*(5), 1103–1123. https://doi.org/10.1037/0278-7393.26.5.1103

Elsherif, M. M., Preece, E., & Catling, J. C. (2023). Age-of-acquisition effects: A literature review. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 49*(5), 812–847. https://doi.org/10.1037/xlm0001215

Fagiolini, M., Pizzorusso, T., Berardi, N., Domenici, L., & Maffei, L. (1994). Functional postnatal development of the rat primary visual cortex and the role of visual experience: Dark rearing and monocular deprivation. *Vision Research, 34*(6), 709–720. https://doi.org/10.1016/0042-6989(94)90210-0

Ferrand, L., & Grainger, J. (1993). The time course of orthographic and phonological code activation in the early phases of visual word recognition. *Bulletin of the Psychonomic Society, 31*(2), 119-122. https://doi.org/10.3758/BF03334157

Ferrand, L., & Grainger, J. (1994). Effects of orthography are independent of phonology in masked form priming. *The Quarterly Journal of Experimental Psychology, 47*(2), 365-382. https://doi.org/10.1080/14640749408401116

Ferrand, L., & Grainger, J. (1996). List context effects on masked phonological priming in the lexical decision task. *Psychonomic Bulletin & Review, 3*(4), 515-519. https://doi.org/10.3758/BF03214557

Fiebach, C. J., Friederici, A. D., Müller, K., von Cramon, D. Y., & Hernandez, A. E. (2003). Distinct brain representations for early and late learned words. *Neuroimage, 19*(4), 1627–1637. https://doi.org/10.1016/S1053-8119(03)00227-1

Flege, J. E., Munro, M. J., & MacKay, I. R. A. (1995). Effects of age of second-language learning on the production of English consonants. *Speech Communication, 16*(1), 1–26. https://doi.org/10.1016/0167-6393(94)00044-B

Fowler, A. E. (1991). How early phonological development might set the stage for phoneme awareness. In S. A. Brady & D. P. Shankweiler (Eds.), *Phonological processes in literacy: A tribute to Isabelle Y. Liberman* (pp. 97-117). Lawrence Erlbaum Associates, Inc.

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: True issues and false trails. *Psychological Bulletin, 123*(1), 71-99. https://doi.org/10.1037/0033-2909.123.1.71

Frost, R., Ahissar, M., Gotesman, R., & Tayeb, S. (2003). Are phonological effects fragile? The effect of luminance and exposure duration on form priming and phonological priming. *Journal of Memory and Language, 48*(2), 346-378. https://doi.org/10.1016/S0749-596X(02)00510-7

Frost, R., Katz, L., & Bentin, S. (1987). Strategies for visual word recognition and orthographical depth: A multilingual comparison. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 104-115. https://doi.org/10.1037//0096-1523.13.1.104

Gaskell, M. G., & Marslen-Wilson, W. D. (1997). Integrating form and meaning: A distributed model of speech perception. *Language and Cognitive Processes, 12*(5-6), 613-656. https://doi.org/10.1080/016909697386646

Gerhand, S. & Barry, C. (1999). Age of acquisition, word frequency, and the role of phonology in the lexical decision task. *Memory & Cognition, 27*(4), 592-602. https://doi.org/10.3758/BF03211553

Ghyselinck, M., Lewis, M. B., & Brysbaert, M. (2004). Age of acquisition and the cumulative-frequency hypothesis: A review of the literature and a new multi-task investigation. *Acta Psychologica, 115*(1), 43-67. https://doi.org/10.1016/j.actpsy.2003.11.002

González-Nosti, M., Barbón, A., Rodríguez-Ferreiro, J., & Cuetos, F. (2014). Effects of the psycholinguistic variables on the lexical decision task in Spanish: A study with 2,765 words. *Behavior Research Methods, 46*(2), 517-525. https://doi.org/10.3758/s13428-013-0383-5

Grainger, J. (1992). Orthographic neighborhoods and visual word recognition. In R. Frost (Ed.), *Orthography, phonology, morphology, and meaning* (pp. 131–146). North-Holland.

Grainger, J., & Ferrand, L. (1994). Phonology and orthography in visual word recognition: Effects of masked homophone primes. *Journal of Memory and Language, 33*(2), 218-233. https://doi.org/10.1006/jmla.1994.1011

Grainger, J., & Ferrand, L. (1996). Masked orthographic and phonological priming in visual word recognition and naming: Cross-task comparisons. *Journal of Memory and Language, 35*(5), 623-647. https://doi.org/10.1006/jmla.1996.0033

Grainger, J., Diependaele, K., Spinelli, E., Ferrand, L., & Farioli, F. (2003). Masked repetition and phonological priming within and across modalities. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(6), 1256-1269. https://doi.org/10.1037/0278-7393.29.6.1256

Havelka, J., & Tomita, I. (2006). Age of acquisition in naming Japanese words. *Visual Cognition, 13*(7-8), 981-991. https://doi.org/10.1080/13506280544000156

Hernandez, A. E., & Li, P. (2007). Age of acquisition: its neural and computational mechanisms. *Psychological Bulletin, 133*(4), 638-650. https://doi.org/10.1037/0033-2909.133.4.638

Hirsh, K. W., Morrison, C. M., Gaset, S., & Carnicer, E. (2003). Age of acquisition and speech production in L2. *Bilingualism: Language and Cognition, 6*(2), 117-128. https://doi.org/10.1037/0033-2909.133.4.638

Izura, C., & Ellis, A. W. (2004). Age of acquisition effects in translation judgement tasks. *Journal of Memory and Language, 50*(2), 165-181. https://doi.org/10.1016/j.jml.2003.09.004

Izura, C., Pérez, M. A., Agallou, E., Wright, V. C., Marín, J., Stadthagen-González, H., & Ellis, A. W. (2011). Age/order of acquisition effects and the cumulative learning of foreign words: A word training study. *Journal of Memory and Language, 64*(1), 32-58. https://doi.org/10.1016/j.jml.2010.09.002

Johnston, R. A., & Barry, C. (2006). Age of acquisition and lexical processing. *Visual Cognition, 13*(7-8), 789-845. https://doi.org/10.1080/13506280544000066

Juhasz, B. J. (2005). Age-of-acquisition effects in word and picture identification. *Psychological Bulletin, 131*(5), 684. https://doi.org/10.1037/0033-2909.131.5.684

Jusczyk, P. W. (1986). Toward a model of the development of speech perception. In J. S. Perkell & D. H. Klatt (Eds.), *Invariance and variability in speech processes* (pp. 1-35). Hillsdale, NJ, US: Lawrence Erlbaum Associates, Inc.

Jusczyk, P. W. (1993). From general to language-specific capacities: The WRAPSA model of how speech perception develops. *Journal of Phonetics*, 21(1-2), 3-28

Kroll, J. F., & De Groot, A. M. (Eds.) (2005). *Handbook of bilingualism: Psycholinguistic approaches*. Oxford University Press.

Kuperman, V., Stadthagen-Gonzalez, H., & Brysbaert, M. (2012). Age-of-acquisition ratings for 30,000 English words. *Behavior research methods, 44*, 978-990. https://doi.org/10.3758/s13428-012-0210-4

Lambon Ralph, M. A., & Ehsan, S. (2006). Age of acquisition effects depend on the mapping between representations and the frequency of occurrence: Empirical and computational evidence. *Visual Cognition, 13*(7-8), 928–948. https://doi.org/10.1080/13506280544000110

Leinenger, M. (2014). Phonological coding during reading. *Psychological Bulletin, 140*(6), 1534-1555. https://doi.org/10.1037/a0037830

Lenth, R. (2023). *emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.8.4.* https://CRAN.R-project.org/package=emmeans

Levelt, W. J., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences, 22*(1), 1-38. https://doi.org/10.1017/S0140525X99001776

Lima, S. D., & Huntsman, L. A. (1997). Sequential dependencies in the lexical decision task. *Psychological Research, 60*(4), 264-269. https://doi.org/10.1007/BF00419412

Lukatela, G., & Turvey, M. T. (2000). An evaluation of the two-cycles model of phonology assembly. *Journal of Memory and Language, 42*(2), 183-207. https://doi.org/10.1006/jmla.1999.2672

Lukatela, G., Eaton, T., Lee, C., & Turvey, M. T. (2001). Does visual word identification involve a sub-phonemic level? *Cognition, 78*(3), B41-B52. https://doi.org/10.1016/S0010-0277(00)00121-9

Lukatela, G., Frost, S. J., & Turvey, M. T. (1998). Phonological priming by masked nonword primes in the lexical decision task. *Journal of Memory and Language, 39*(4), 666-683. https://doi.org/10.1006/jmla.1998.2599

Mackay, I. R. A., & Flege, J. E. (2004). Effects of the age of second language learning on the duration of first and second language sentences: The role of suppression. *Applied Psycholinguistics, 25*(3), 373–396. https://doi.org/10.1017/S0142716404001171

Metsala, J. L., & Walley, A. C. (1998). Spoken vocabulary growth and the segmental restructuring of lexical representations: Precursors to phonemic awareness and early reading ability. In J. L. Metsala & L. C. Ehri (Eds.), *Word recognition in beginning literacy* (pp. 89-120). Lawrence Erlbaum Associates Publishers.

Monaghan, J., & Ellis, A. W. (2002a). What, exactly, interacts with spelling sound consistency in word naming? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*(1), 183–206. https://doi.org/10.1037/0278-7393.28.1.183

Monaghan, J., & Ellis, A. W. (2002b). Age of acquisition and the completeness of phonological representations. *Reading and Writing, 15*(7-8), 759–788. https://doi.org/10.1023/A:1020958722472

Monaghan, P., & Ellis, A. W. (2010). Modeling reading development: Cumulative, incremental learning in a computational model of word naming. *Journal of Memory and Language, 63*(4), 506–525. https://doi.org/10.1016/j.jml.2010.08.003

Moore, V., & Valentine, T. (1998). The effect of age-of-acquisition on speed and accuracy of naming famous faces. *Quarterly Journal of Experimental Psychology, 51*, 485–513. https://doi.org/10.1080/713755779

Morrison, C. M., Chappell, T. D., & Ellis, A. W. (1997). Age of acquisition norms for a large set of object names and their relation to adult estimates and other variables. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 50A*(3), 528-559. https://doi.org/10.1080/027249897392017

Perea, M., & Carreiras, M. (1998). Effects of syllable frequency and syllable neighbourhood frequency in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance 24*(1), 134-144. https://doi.org/10.1037/0096-1523.24.1.134

Perea, M., & Carreiras, M. (2003). Sequential effects in the lexical decision task: The role of the item frequency of the previous trial. Quarterly Journal of Experimental Psychology Series a Human Experimental Psychology, 56(3), 385-402. https://doi.org/10.1080/02724980244000387

Perea, M., & Rosa, E. (2002). The effects of associative and semantic priming in the lexical decision task. *Psychological Research, 66*, 180-194. https://doi.org/10.1007/s00426-002-0086-5

Pérez, M. A. (2007). Age of acquisition persists as the main factor in picture naming when cumulative word frequency and frequency trajectory are controlled. *The Quarterly Journal of Experimental Psychology, 60*(1), 32-42. https://doi.org/10.1080/17470210600577423

Pérez, M. A., Alameda, J. R. & Cuetos, F. (2003). Frecuencia, longitud y vecindad ortográfica de las palabras de 3 a 16 letras del Diccionario de la Lengua Española (RAE, 1992) [Frequency, length, and orthographic neighborhood of words from 3 to 16 letters from the Dictionary of the Spanish Language (RAE, 1992)]. *Revista Electrónica de Metodología Aplicada, 8*(2), 1-10. Retrieved from https://dialnet.unirioja.es/servlet/articulo?codigo=795198

Pérez, M., & Navalón, C. (2005). Objective-AoA norms for 175 names in Spanish: Relationships with other psycholinguistic variables, estimated AoA, and data from other languages. *European Journal of Cognitive Psychology, 17*(2), 179-206. https://doi.org/10.1080/09541440340000547

Perfetti, C. A., & Bell, L. (1991). Phonemic activation during the first 40 ms of word identification: Evidence from backward masking and priming. *Journal of Memory and Language, 30*(4), 473-485. https://doi.org/10.1016/0749-596X(91)90017-E

Perret, C., Bonin, P., & Laganaro, M. (2014). Exploring the multiple-level hypothesis of AoA effects in spoken and written object naming using a topographic ERP analysis. *Brain and Language, 135*, 20-31. https://doi.org/10.1016/j.bandl.2014.04.006

Pollatsek, A., Perea, M., & Carreiras, M. (2005). Does conal prime CANAL more than cinal? Masked phonological priming effects in Spanish with the lexical decision task. *Memory & Cognition, 33*(3), 557-565. https://doi.org/10.3758/BF03193071

R Core Team (2023). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Raman, I. (2006). On the age-of-acquisition effects in word naming and orthographic transparency: Mapping specific or universal? *Visual Cognition, 13*(7-8), 1044-1053. https://doi.org/10.1080/13506280500153200

Ramanujan, K., & Weekes, B. S. (2020). Predictors of lexical retrieval in Hindi–English bilingual speakers. *Bilingualism: Language and cognition, 23*(2), 265-273. https://doi.org/10.1017/S1366728918001177

RStudio Team (2023). *RStudio: Integrated Development Environment for R*. RStudio, PBC, Boston, MA URL http://www.rstudio.com/

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime: User's guide*. Psychology Software Incorporated.

Sebastián, N., Martí, M. A., Carreiras, M. F., & Cuetos, F. (2000). LEXESP, léxico informatizado del Español [LEXESP, computerized lexicon of Spanish]. Edicions Universitat de Barcelona. Retrieved from http://www.publicacions.ub.edu/ficha.aspx?cod=05096e

Soetens, E. (1998). Localizing sequential effects in serial choice reaction time with the information reduction procedure. *Journal of Experimental Psychology: Human Perception and Performance, 24*(2), 547-568. https://doi.org/10.1037/0096-1523.24.2.547

Stadthagen-Gonzalez, H., Bowers, J. S., & Damian, M. F. (2004). Age of acquisition effects in visual word recognition: Evidence from expert vocabularies. *Cognition, 93*(1), 11–26. https://doi.org/10.1016/j.cognition.2003.10.009

Stadthagen-Gonzalez, H., Damian, M. F., Pérez, M. A., Bowers, J. S., & Marín, J. (2009). Name-picture verification as a control measure for object naming: A task analysis and norms for a large set of pictures. Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 62(8), 1581–1597. https://doi.org/10.1080/17470210802511139

Steyvers, M., & Tenenbaum, J. B. (2005). The large-scale structure of semantic networks: Statistical analyses and a model of semantic growth. *Cognitive Science, 29*(1), 41-78. https://doi.org/10.1207/s15516709cog2901_3

Vitkovitch, M., & Tyrrell, L. (1995). Sources of disagreement in object naming. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 48*(4), 822-848. https://doi.org/10.1080/14640749508401419

Wilson, M. (1988). MRC psycholinguistic database: Machine-usable dictionary, version 2.00. *Behavior Research Methods, Instruments, & Computers, 20*(1), 6-10. https://doi.org/10.3758/BF03202594

Wilson, M. A., Cuetos, F., Davies, R., & Burani, C. (2013). Revisiting age-of-acquisition effects in Spanish visual word recognition: The role of item imageability. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*(6), 1842-1859. https://doi.org/10.1037/a0033090

Wilson, M. A., Ellis, A. W., & Burani, C. (2012). Age-of-acquisition affects word naming in Italian only when stress is irregular. *Acta Psychologica, 139*(3), 417–424. https://doi.org/10.1016/j.actpsy.2011.12.012

Yum, Y. N., & Law, S. P. (2019). Interactions of age of acquisition and lexical frequency effects with phonological regularity: An ERP study. *Psychophysiology, 56*(10), e13433. https://doi.org/10.1111/psyp.13433

Zevin, J. D., & Seidenberg, M. S. (2002). Age of acquisition effects in word reading and other tasks. *Journal of Memory and Language, 47*(1), 1–29. https://doi.org/10.1006/jmla.2001.2834

Ziegler, J. C., Ferrand, L., Jacobs, A. M., Rey, A., & Grainger, J. (2000). Visual and phonological codes in letter and word recognition: Evidence from incremental priming. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, 53(3), 671-692. https://doi.org/10.1080/713755906