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

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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 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 Elsner et al., 2023; Johnston & Barry, 2006; Juhász, 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 processing. 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.
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 Ehсан (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 /æ/ sound in Spanish allows the correct reading of words such as pena (sadness), pan (bread), apnea (apnoea), or papa (dad), irrespective of when these words entered the vocabulary of the individual. In fact, the literature review by Elshenf 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; Ramnujan & 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 (Brainerd & 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 ‘train’) are used as primes for target words (e.g., ‘train’) in lexical decision tasks (Ferrand & Grainger, 1993; 1994; Frost, 1998; Lukatela et al., 1998). This priming effect observed for pseudohomophones (e.g., ‘lais’ > ‘lair’) is generally larger than that found for primes similar to only the target in their orthography (e.g., ‘left’ > ‘lair’) (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 al., 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) word written 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 c) 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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Experimental words</th>
<th>Filler words</th>
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<td>Early</td>
<td>Late</td>
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<tr>
<td>Objective AoA</td>
<td></td>
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<tr>
<td>Objective AoA</td>
<td>41.1 (27-53)</td>
<td>83.3 (36-143)</td>
</tr>
<tr>
<td>Subjective AoA</td>
<td>4.0 (2.9-6.7)</td>
<td>3.6 (3.5-6.7)</td>
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<tr>
<td>WF-LEXESP</td>
<td>11.4 (1-29)</td>
<td>11.8 (0-34)</td>
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<tr>
<td>CD-ESPAL</td>
<td>17.2 (7-20)</td>
<td>11.6 (0-39)</td>
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<tr>
<td>Imageability</td>
<td>4.9 (1-14)</td>
<td>4.1 (0-14)</td>
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<tr>
<td>Concreteness</td>
<td>6.2 (5.8-6.5)</td>
<td>6.1 (5.6-6.5)</td>
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<tr>
<td>N-LET</td>
<td>6.1 (4.9-6.6)</td>
<td>6.1 (5.5-6.5)</td>
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<td>N-SYl</td>
<td>5.6 (4-8)</td>
<td>6.0 (4-8)</td>
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<td>N-PHON</td>
<td>2.4 (2-3)</td>
<td>2.5 (2-3)</td>
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<tr>
<td>N</td>
<td>5.3 (3-8)</td>
<td>5.7 (4-8)</td>
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<tr>
<td>NF</td>
<td>5.5 (0-19)</td>
<td>5.5 (0-29)</td>
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<tr>
<td>E-ESPAL</td>
<td>7754 (103-26099)</td>
<td>9013 (60-26099)</td>
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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. E-SYl, positional syllable-frequency of the first syllable from Sebastián et al.

In months. In years (from 1 to 11). Per Million. Percentage of movies.

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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 = 4.9, 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 /ˈvwo/); b) orthographically related primes were pseudowords sharing more letters than phonemes per position with the target words (e.g., gýko-BÚHO, /ˈgyko/ 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., gýfe-BÚHO, /ˈgyfe/ 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.

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, . 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 linear 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 high-

<table>
<thead>
<tr>
<th>Type of prime</th>
<th>Letters</th>
<th>Phonemes</th>
<th>Syllables $^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phonologically related (pseudohomophones)</td>
<td>52 (.4)</td>
<td>100 (0)</td>
<td>100 (0)</td>
</tr>
<tr>
<td>Orthographically related</td>
<td>58 (.1)</td>
<td>20 (.2)</td>
<td>5 (.1)</td>
</tr>
<tr>
<td>Unrelated</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$p$ values (Phonological vs. orthographic primes t-test)</td>
<td>.466</td>
<td>&lt; .000</td>
<td>&lt; .000</td>
</tr>
</tbody>
</table>

$^a$As a phonological unit

Table 2 Mean percentage (and standard deviation) of shared units per position between primes and targets in Experiment 1
est 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 emmeans 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 = 0.0000104, 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 = 0.00000612, 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, /ko 나/ - /ka 나/), but a diminished priming effect when they share only the first letter but not the first sound (cinal-CANAL, /o 나/ - /ka 나/). 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 /a:/, can be spelled as ‘e,’ ‘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 subitle 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 /kændəl/); 2) priming another word with which it did not share any letter or phoneme in the same position (e.g., jera-CANDLE, sounding /dʒərə/—/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 non-
associated 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 a homophonic prime and unrelated prime (i.e., control condition). Appendix B provides additional details.

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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Early</th>
<th>Late</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AoA-MCE&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.6 (23-50)</td>
<td>95.9 (36-140)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>AoA-KSB&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.0 (2.7-8.1)</td>
<td>7.0 (5.1-10.8)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>WF-CELEX&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.7 (1-12)</td>
<td>4.8 (0-14)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>WF-ELP&lt;sup&gt;d&lt;/sup&gt;</td>
<td>8.7 (1-22)</td>
<td>5.7 (0-19)</td>
<td>.135</td>
</tr>
<tr>
<td>CD-ELP</td>
<td>3 (0-6)</td>
<td>2.1 (0-8)</td>
<td>1.98</td>
</tr>
<tr>
<td>IMG-MCE&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6.3 (5.6-6.7)</td>
<td>5.9 (5.2-6.5)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>IMG-MRC&lt;sup&gt;e&lt;/sup&gt;</td>
<td>597 (574-617)</td>
<td>586 (536-619)</td>
<td>.289</td>
</tr>
<tr>
<td>CON-MRC&lt;sup&gt;e&lt;/sup&gt;</td>
<td>602 (560-628)</td>
<td>580 (433-616)</td>
<td>.277</td>
</tr>
<tr>
<td>CON-BWK&lt;sup&gt;e&lt;/sup&gt;</td>
<td>4.9 (4.4-5.0)</td>
<td>4.7 (3.3-5.0)</td>
<td>.168</td>
</tr>
<tr>
<td>N-Let</td>
<td>5.7 (3-8)</td>
<td>5.7 (4-8)</td>
<td>.905</td>
</tr>
<tr>
<td>N-Syl</td>
<td>1.7 (1-3)</td>
<td>1.9 (1-3)</td>
<td>.394</td>
</tr>
<tr>
<td>N-Phon</td>
<td>4.6 (3-7)</td>
<td>4.7 (3-6)</td>
<td>.876</td>
</tr>
<tr>
<td>N</td>
<td>2.9 (0-8)</td>
<td>1.6 (0-10)</td>
<td>.163</td>
</tr>
<tr>
<td>NF+</td>
<td>1.4 (0-5)</td>
<td>.8 (0-5)</td>
<td>.281</td>
</tr>
<tr>
<td>Bigram-Token&lt;sup&gt;e&lt;/sup&gt;</td>
<td>464 (44-1760)</td>
<td>470 (112-1290)</td>
<td>.965</td>
</tr>
<tr>
<td>Bigram-Type</td>
<td>27 (3-67)</td>
<td>32 (12-74)</td>
<td>.350</td>
</tr>
</tbody>
</table>

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, substitute 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-Watch (Davis, 2003). NF, number of neighbours with frequency higher than that of the target word, from N-Watch (Davis, 2003).

<sup>a</sup>In months. <sup>b</sup>Per Million. <sup>c</sup>Scale from 1-10. <sup>d</sup>Scale from 0-10. <sup>e</sup>Scale from 1-5

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).

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. 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.

(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 latency data as a function of AoA, AoA*Type, Type*Age, Type*AoA, and Age. As in Experiment 1, we also obtained a LMM of the latency data as a function of AoA, AoA*Type, Type*Age, Type*AoA, and Age. As in Experiment 1, we also obtained a LMM of the latency data as a function of AoA, AoA*Type, Type*Age, Type*AoA, and Age. As in Experiment 1, we also obtained a LMM of the latency data as a function of AoA, AoA*Type, Type*Age, Type*AoA, and Age.
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 $1/RT \sim \text{PrimeType*TargetAoA} + (1 + \text{PrimeType*TargetAoA} | \text{Participant}) + (1 | \text{Target})$. 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 ($\text{estimate} = 0.000112, t(35.9) = 3.270, p = .002$; 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 ($\text{estimate} = 0.000037, t(38) = 2.483, p = .018$; 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 ($\text{estimate} = 0.0000502, t(38) = 2.060, p = .046$; 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](image-url)

**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-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 & Elston, 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 appendices (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/kv837/.

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

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