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Age-of-acquisition and word frequency in the lexical decision task: Further evidence from the French language

Patrick Bonin, Marylène Chalard, Alain Méot, and Michel Fayol

CNRS & Université Blaise Pascal, Clermont-Ferrand, France

Abstract

The influence of objective word frequency and age-of-acquisition (AoA) was investigated in three visual lexical decision experiments conducted in French. In Experiment 1, an AoA effect was found on RTs with word frequency controlled for, and in Experiment 2 a word frequency effect was observed on RTs with AoA controlled for. Experiment 3 used a large set of items and multiple regression analyses. The analyses revealed strong and reliable AoA and word frequency effects as well as an interaction between the two variables, with the result that an AoA effect was observed on low-frequency words only, replicating a previously reported interaction in lexical decision in English (Gerhand & Barry, 1999). The implications of the findings are discussed.

Key words: age-of-acquisition, word frequency, lexical decision.

Correspondence should be sent to Patrick Bonin, Laboratoire de Psychologie Sociale de la Cognition et de Psychologie Cognitive (LAPSCO/CNRS), Université Blaise Pascal, 34 avenue Carnot, 63037 Clermont-Ferrand, France (Email: Patrick.Bonin@srvpsy.univ-bpclermont.fr)

INTRODUCTION

A growing body of evidence indicates that age-of-acquisition (AoA) is a key variable in a wide variety of verbal tasks with the result that words acquired early in life are processed faster than words acquired later. AoA effects have been robustly found in spoken picture naming (Barry, Morrison, & Ellis, 1997; Bonin, Fayol, & Chalard, 2001; Bonin, Chalard, Méot, & Fayol, in press; Carroll & White, 1973; Hodgson & Ellis, 1998; Lachman, 1973; Lachman, Schaffer, & Henrikus, 1974; Morrison, Chappell, & Ellis, 1997; Morrison, Ellis, & Quinlan, 1992), written picture naming (Bonin et al., 2001; Bonin et al., in press), face naming (Moore & Valentine, 1998), category instance naming (Loftus & Suppes, 1972), word completion (Gilhooly & Gilhooly, 1979), reading aloud (Brown & Watson, 1987; Coltheart, Laxon, & Keating, 1988; Gerhand & Barry, 1998; Gilhooly & Logie, 1981; Morrison & Ellis, 1995; Yamazaki, Ellis, Morrison, & Lambon Ralph, 1997), visual lexical decision (e.g., Brysbaert, 1996; Butler & Hains, 1979; Gerhand & Barry, 1999; Morrison & Ellis, 1995; Turner, Valentine, & Ellis, 1998), perceptual identification (Lyons, Teer, & Rubenstein, 1978), and auditory lexical decision (e.g., Cirrin, 1984; Turner et al., 1998). For a long time, AoA was a neglected variable in psycholinguistics. However, this situation has changed somewhat in recent years.

Word frequency is also a well-known variable which has been reliably found to affect performance in a huge variety of verbal tasks such as picture naming (Bonin, Fayol, & Gombert, 1998; Humphreys, Riddoch, & Quinlan, 1988; Huttenlocher & Kubicek, 1983; Jescheniak & Levelt, 1994; Oldfield & Wingfield, 1965), reading aloud (Forster & Chambers, 1973; Frederiksen & Kroll, 1976; Monsell, Doyle, & Haggard, 1989; Rayner, 1977; Strain, Patterson, & Seidenberg, 1995), and lexical decision (e.g., Forster & Chambers, 1973). It must be stressed, however, that many reports of word frequency effects have been made without any consideration of AoA (Gerhand & Barry, 1999).

Morrison et al. (1992) adopted a somewhat provocative stance in claiming that word frequency effects were putative AoA effects on the basis of regression analyses that took into account both word frequency and AoA and that showed strong and reliable effects of AoA but not word frequency (see also Carroll & White, 1973, and, using a semi-factorial design in reading aloud, Morrison & Ellis, 1995). Since then, other studies have demonstrated both AoA and word frequency effects in visual lexical decision (Brysbaert, 1996; Brysbaert, Lange, & Van Wijnendaele, 2000; Buttler & Hains, 1979; Gerhand & Barry, 1999; Morrison & Ellis, 2000; Whaley, 1978), picture naming (Barry et al., 1997; Ellis & Morrison, 1998; Snodgrass & Yuditsky, 1996), and reading aloud (Brysbaert et al., 2000; Gerhand & Barry, 1998; Morrison & Ellis, 2000).

As far as visual lexical decision is concerned, i.e., the task on which we focused in the present study, Gerhand and Barry (1999) have provided evidence for the hypothesis that AoA affects the output phonological lexicon (or more precisely, the production of lexical phonology) whereas word frequency has its primary locus in the input (visual) lexicon (i.e., the visual recognition of words, see also Gerhand & Barry, 1998, for related evidence in support of this hypothesis). Two different loci for word frequency and AoA in word recognition have been proposed by Gerhand and Barry (1999) on the basis of the following rationale. In a series of experiments using the visual lexical decision task, Gerhand and Barry (1999) found main effects of both AoA and word frequency and an interaction between the two variables. The interaction indicated that the AoA effect was larger for low- than for high-frequency words. In experiments that were designed to reduce the contribution of phonology, they observed that the manipulations intended to interfere with phonological coding reduced the AoA effect but did not eliminate it, whereas the word frequency effect remained unaffected. According to these authors, the word frequency effect has its locus at the level of access to orthographic representations with the result that orthographic representations corresponding to high-frequency words should be activated more rapidly than orthographic representations corresponding to low-frequency words. The effect of AoA in lexical decision could therefore be explained by assuming that AoA affects the *lexical* phonological representations (see also Morrison & Ellis, 1995, for such an interpretation) which are thought to be automatically consulted in this task. Therefore, the phonological representations of early-acquired words should be accessed more quickly than the phonological representations of late-acquired words. Given that AoA is thought to be located at the level of lexical phonological representations, the manipulations designed to interfere with phonological coding should only modulate the AoA effect, as the authors indeed observed. To account for the interaction between AoA and word frequency, Gerhand and Barry

(1999) have proposed that, in lexical decision, activation from different sources flows in a cascaded manner (see in particular Coltheart, Rastle, Perry, Langdon, & Ziegler, 2000, for a model which assumes cascaded processing in word recognition and reading aloud) so that correct "yes" responses to word stimuli are made whenever the activation of either the orthographic or the phonological representation corresponding to a given word reaches a threshold level. Accordingly, for high-frequency words, the orthographic representations are activated rapidly with the result that correct "yes" responses will be made on the basis of these representations before the corresponding phonological representations have reached threshold level. As a result, for these words, no AoA effect is detected. In the case of low-frequency words, the orthographic representations take longer to reach threshold and decisions can therefore be made on the basis of the phonological representations which reach threshold. In this latter case, an AoA effect is apparent.

As far as French is concerned, the topic of AoA in relation to word frequency has not as yet been widely studied. In two recent studies, we have provided evidence for AoA effects on onset naming latencies in both spoken and written picture naming (Bonin et al., 2001; Bonin et al., in press). More precisely, in Bonin et al. (2001), we found that AoA was significant on both spoken and written naming latencies when word frequency was controlled for, whereas word frequency was not reliable when AoA was controlled for. However, in this study, small sets of items were used and it has been claimed that word frequency effects are more easily detected when large sets of items are used. Moreover, in the experiments examining word frequency, AoA was primarily controlled on early acquired words. This latter point is important given that Barry et al. (1997) reported an interaction between AoA and word frequency in spoken picture naming, indicating that word frequency is reliable only for late acquired words. To circumvent the potential shortcomings of Bonin et al.'s study (2001), in another picture naming study (Bonin et al., in press) large sets of items and regression analyses were used to address further the impact of word frequency and AoA in both spoken and written picture naming. Again, strong and reliable AoA effects were found on picture naming latencies but word frequency did not emerge as an independent predictor nor did it interact with word frequency.

In the present study, in accordance with the perspective proposed by Gerhand and Barry (1999) and reviewed above, we considered the working hypothesis that word frequency has its primary locus in the visual-orthographic input lexicon whereas AoA has its locus at or around the level of the output phonological lexicon. According to this hypothesis, word frequency effects are most likely to emerge in tasks that index visual-orthographic representations, and AoA effects are predicted in tasks that mobilise *output* (phonological) representations.[1]

Therefore, in the light of studies which have reported effects of both AoA and word frequency in lexical decision (Gerhand & Barry, 1999), we decided to use the lexical decision task in an attempt to provide additional evidence for these effects using French stimuli.[2] Visual lexical

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1. It might be asked why the phonological *output* lexicon as opposed to the phonological *input* lexicon should be required. The reason is because strong AoA effects have been found in tasks that unambiguously require access to the output phonological lexicon such as picture naming or word naming, whereas there is little clear evidence for AoA effects in tasks that clearly require access to the input phonological lexicon such as auditory word recognition thresholds (e.g., Gilhooly & Logie, 1981).

2. It might be argued that the choice of the lexical decision task alone is not a valid means of revealing the involvement of phonological codes since (1) lexical decisions might be thought (on a rather conservative account) to be performed on the basis of orthographic codes; (2) related to the previous point, the visual lexical decision task does not logically require the involvement of phonological codes; (3) the lexical decision task cannot by itself distinguish between effects that occur at the level of the phonological output lexicon and effects that occur at the level of orthographic codes and, therefore, it would have been advisable to include a task that clearly involves the phonological output lexicon. However, it is noteworthy that a number of studies in the word recognition literature have provided evidence that phonology is generated in the course of processing written words in tasks where it is not logically required and may even hinder performance, thus strongly suggesting that phonology is activated automatically (e.g., Perfetti, Bell, & Delaney, 1988; Ziegler & Jacobs, 1995). More particularly, in the case of lexical decision, there is evidence for the involvement of phonological representations as exhibited for instance by the so-called "pseudohomophone effect" (pseudohomophones take longer to reject than nonhomophonic nonwords, e.g., Besner & Davelaar, 1983; Seidenberg, Petersen, MacDonald, & Plaut, 1996). Related to point (3), it is important to note that we have indeed already performed some experiments, using the same stimuli as those used in the following lexical decision experiments, in spoken picture naming (Bonin et al., 2001; Bonin et al., in press), a task which clearly requires access to the spoken output lexicon and with which the results obtained in lexical decision could be compared.

decision is one of the most frequently used tasks to investigate word recognition. As stated above, the word frequency effect is robustly found in visual lexical decision tasks.

Adopting Gerhand and Barry's (1998) perspective, we think it is very important to assess both the robustness of independent effects of word frequency and AoA in visual word recognition, and their interaction, because most of the models of word recognition have placed a strong emphasis on accounts of word frequency but not of AoA. It is therefore very important to determine the generality of these effects in different languages before any strong conclusions can be drawn. As a result, the goal of the present study was to further determine whether AoA and word frequency effects and the interaction between the two variables could be replicated in French in the visual lexical decision task. From an empirical point of view, another major question is to determine whether AoA or word frequency has to be controlled for in future studies of word recognition.

In the first two experiments, a semi-factorial design was used. In Experiment 1, AoA was manipulated with word frequency controlled for whereas in Experiment 2, word frequency was manipulated with AoA controlled for. It is important to remember that the same word stimuli as used in Bonin et al.'s (2001) picture naming study, which indicated a lack of any reliable effect of word frequency but a reliable effect of AoA, were employed. In Experiment 3, a large set of items was used and regression analyses were performed. This latter experiment allowed us to test for the existence of an interaction between word frequency and AoA in lexical decision with French stimuli as reported for English by Gerhand and Barry (1999) in a fully factorial design. It is fair to say that this interaction has, to our knowledge, solely been reported in English. It should be again borne in mind that in Experiment 3, the word stimuli included those used in the Bonin et al. study (in press), in which no word frequency effect was found on either spoken or written picture naming latencies.

EXPERIMENT 1

Method

Participants. Thirty psychology students from Blaise Pascal University were recruited. All were native speakers of French and had normal or corrected-to-normal vision. The students received course credits for their participation.

Stimuli. The experimental stimuli consisted of 36 words selected from the Alario and Ferrand (1999) database and 36 nonwords. The statistical characteristics corresponding to the word stimuli are presented in Table 1. The list of the word stimuli is provided in Appendix 1.

Table 1
Statistical characteristics of the word stimuli used in Experiment 1

	EA			LA			*P*
	Mean	*SD*	Min-max	Mean	*SD*	Min-max	values
Conceptual familiarity*	3.61	0.99	[1.50-4.93]	2.59	1.29	[1.07-4.80]	<.01
Image variability*	3.36	0.68	[2.30-4.50]	2.74	0.67	[1.93-4.07]	<.01
AoA*	1.53	0.23	[1.19-1.88]	2.64	0.62	[2.04-4.15]	<.001
Word frequency**	55	58	[3-206]	32	26	[2-105]	ns
Orthographic length	6.06	1.43	[4-9]	6.28	1.27	[4-9]	ns
Phonological length	4.33	1.46	[2-8]	4.72	0.96	[3-7]	ns
Nb of syllables	1.67	0.69	[1-3]	1.83	0.51	[1-3]	ns
Nb of orthographic neighbours	2.17	2.15	[0-8]	1.50	2.23	[0-6]	ns
Nb of higher frequency neighbours	0.44	0.98	[0-4]	0.33	0.69	[0-2]	ns
GP consistency***	74	15	[43-99]	75	13	[54-92]	ns
Bigram frequency****	1347	743	[347-3113]	1104	664	[433-2721]	ns

Notes: EA = early-acquired words; LA = late-acquired words; *P* values = *p* values corresponding to the difference between the means (ns = not significant); Nb = number; GP = grapheme-phoneme; * from Alario & Ferrand (1999); ** word frequency per million (from Imbs, 1971); *** using Véronis' procedure; **** from Content & Radeau (1988).

Eighteen words were early acquired words and the 18 remaining words were late acquired words. AoA scores were selected from Alario and Ferrand (1999). To collect AoA scores, Alario and Ferrand (1999) asked twenty-six adults to estimate the age at which they thought they had learned each of the words in either their spoken or written form using a five-point scale (with 1 = learned at 0-3 years and 5 = learned at 12+, with 3-year age bands in between). As shown in Table 1, the two sets of words were matched on word frequency (word frequency values per million were taken from Imbs, 1971), number of letters, phonemes, syllables, number of orthographic neighbours, number of higher frequency orthographic neighbours, bigram frequency, and grapheme-to-phoneme consistency. Due to the stringent selection restrictions, conceptual familiarity and image variability were not controlled for. As a result, these two variables were included as covariates in the by-item analyses. The measures of conceptual familiarity and image variability were taken from Alario and Ferrand (1999). Familiarity refers to the familiarity of the concept presented in a picture. It was measured on a five-point scale (1 = a very unfamiliar object, 5 = a very familiar object). Image variability measures indicate whether the name of an object evokes few or many different images. It was also rated on a five-point scale (1 = few images, 5 = many images). The number of orthographic neighbours (i.e., the number of different words that can be created by changing one letter of the target word, while preserving letter positions) and the number of higher frequency orthographic neighbours were obtained from the Brulex database (Content, Mousty, & Radeau, 1990). Bigram frequency values were selected from Content and Radeau (1988). Finally, grapheme-to-phoneme consistency scores were computed using Véronis' (1988) procedure.

The 36 nonwords were created by first selecting for each experimental word, a word that had an identical number of letters and the same initial letter. Then, for each experimental word, the corresponding nonword was obtained by altering one letter in the yoked word. For example, the word "*pomme*" was yoked to the word "*plume*", and the nonword "*plude*" was obtained by substituting the letter *d* for the letter *m*. All the nonwords had to be pronounceable but nonhomophonic to real words. Twenty stimuli were used as warm-ups.

Apparatus. The experiment was run using PsyScope version 1.2 (Cohen, MacWhinney, Flatt, & Provost, 1993) on an Apple PowerMac computer. The computer controlled the presentation of the stimuli and recorded the RTs.

Procedure. Participants were tested individually. They were told that for each letter string presented in the centre of the screen (the stimuli were presented in 48-point Geneva font), they would have to decide, as quickly as possible, whether or not the letter string corresponded to a real word. The stimuli were randomly presented to the participants. They responded by means of two keys that were assigned the responses "word" and "nonword", respectively. Word responses were always assigned to the dominant hand. A trial began with a visual ready signal ("*") presented on the screen for 500 ms and followed by the stimulus which remained in the centre of the screen until the participant's response. The next trial was initiated 2000 ms later. The experiment started with 20 practice trials. The entire session lasted about 15 minutes.

Results

Trials in which stimuli were responded to erroneously (i.e., "word response" to a nonword stimulus or the reverse) were discarded from the RT analyses (3.94%). RTs exceeding two standard deviations above the participant and item means were also excluded (1.62%). Overall, 5.56% of the RT data were discarded. *T*-tests were carried out on the participant means ($t1$) and on the item means ($t2$). *T*-tests were conducted separately on RTs and on errors. Conceptual familiarity and image variability were included as covariates in the analyses by items. In all the experiments, the conventional level of .05 for statistical significance was adopted.

Two kinds of analyses were performed. In the first, lexicality was introduced as the experimental factor, whereas in the second, only words were considered with AoA as the experimental factor. The mean RTs and standard deviations of these means are provided for each word stimulus in Appendix 1.

As expected, words were responded to faster than nonwords (616 versus 761 ms, respectively), $t1(29) = -6.14$, $SE = 23.57$; $t2(70) = -10.725$, $SE = 13.32$. There was no significant lexicality effect on errors (3.33 versus 4.54% for words and nonwords, respectively), $t1(29) = -0.99$, $SE = .012$ and $t2(70) = -1.07$, $SE = .011$.

Table 2 shows the mean RTs as a function of AoA, their standard deviations and the percentages of errors. Responses were faster to EA words than to LA words. The AoA effect was significant in the by-participant analysis, $t1(29) = -6.52$, $SE = 8.58$, and failed to reach significance in the by-item analysis, $t2(32) = -1.87$, $SE = 21.42$, $p = .07$. (None of the covariate factors were significant in the analysis by items.) There were fewer errors on EA words than on LA words but this effect was only significant for participants, $t1(29) = -2.57$, $SE = .012$; $t2(32) = -.76$, $SE = .015$.

Table 2
Mean RTs on words in ms (RT), standard deviations of these means (*SD*), and error rates (E) in percentages as a function of AoA (Experiment 1) and as a function of word frequency (Experiment 2). Mean spoken latencies (in ms), standard deviations of these means, and error rates in percentages obtained in the Bonin et al. (2001) study are given in parentheses

Experiment 1					
	EA			LA	
RT	*SD*	E	RT	*SD*	E
588 (753)	61 (63.8)	1.85 (1.8)	644 (900)	64 (113.5)	4.81 (6.4)
Experiment 2					
	HF			LF	
RT	*SD*	E	RT	*SD*	E
559 (745)	80 (78.8)	1.57 (2.5)	608 (755)	87 (89.4)	1.76 (5.1)

Notes: EA = early-acquired words, LA = late-acquired words; HF = high-frequency words, LF = low-frequency words.

EXPERIMENT 2

Method

Participants. Thirty psychology students were recruited from the same pool as in Experiment 1 and were given course credits for their participation. None had taken part in Experiment 1.

Stimuli. The experimental stimuli included 34 words taken from the Alario and Ferrand (1999) database and 34 nonwords. The statistical characteristics corresponding to the word stimuli are presented in Table 3. The list of the word stimuli is provided in Appendix 2.

Table 3
Statistical characteristics of the word stimuli used in Experiment 2

	HF			LF			*P*
	Mean	*SD*	Min-max	Mean	*SD*	Min-max	values
Conceptual familiarity*	3.80	0.71	[2.63-4.93]	3.56	0.92	[1.87-4.90]	ns
Image variability*	3.68	0.55	[2.83-4.70]	3.04	0.60	[2.23-4.10]	<.01
AoA*	1.58	0.18	[1.38-1.88]	1.66	0.23	[1.23-1.92]	ns
Word frequency**	178	153	[53-605]	10	7	[1-29]	<.001
Orthographic length	5.71	0.99	[4-8]	6.53	1.97	[3-10]	ns
Phonological length	4.18	1.07	[3-7]	4.59	1.23	[3-8]	ns
Nb of syllables	1.59	0.62	[1-3]	1.82	0.53	[1-3]	ns
Number of orthographic neighbours	1.35	1.46	[0-6]	2.59	3.76	[0-14]	ns
Nb of higher frequency neighbours	0.00	0.00	[0-0]	0.65	1.27	[0-5]	= .052
GP consistency***	74	12	[49-99]	74	11	[51-97]	ns
Bigram frequency****	1245	584	[282-2393]	1472	773	[422-3836]	ns

Notes: HF = high-frequency words; LF = low-frequency words; *P* values = *p* values corresponding to the difference between the means; Nb = number; GP = grapheme-phoneme; * from Alario & Ferrand (1999); ** word frequency per million (from Imbs, 1971); *** using Véronis' procedure; **** from Content & Radeau (1988).

Seventeen words corresponded to high-frequency words and the 17 remaining words corresponded to low-frequency words. As in Experiment 1, the frequency values were taken from Imbs (1971). The two sets of words were matched on AoA, conceptual familiarity, number of letters, phonemes, syllables, number of orthographic neighbours, bigram frequency, and grapheme-to-phoneme consistency. However, it was not possible to control for image variability and number of higher orthographic neighbours. Therefore, these variables were included as covariates in the by-item analyses. Nonwords were created using the same procedure as in Experiment 1. Twenty stimuli were used as practice trials.

Apparatus and procedure. These were the same as in Experiment 1.

Results

The same criteria as used in Experiment 1 were applied to exclude trials: 4.12% of the observations were excluded because they were responded to erroneously. Latencies exceeding two standard deviations above the participant and item means were removed (1.57%). Overall, 5.69% of the data were discarded from the RT analyses. As in Experiment 1, two types of analyses were performed: one using Lexicality as a factor and one on words only using Frequency as a factor. The mean RTs and standard deviations of these means for individual words can be found in Appendix 2.

RTs on words were faster than RTs on nonwords (584 versus 749 ms), $t1(29) = -9.97$, $SE = 16.56$; $t2(66) = -13.28$, $SE = 12.62$. There were fewer errors on words than on nonwords (1.67 versus 6.57%), $t1(29) = -2.69$, $SE = .018$; $t2(66) = -3.78$, $SE = .013$.

Table 2 presents the mean RTs as a function of word frequency, their standard deviations and the error rates. HF words yielded shorter RTs than LF words, $t1(29) = -7.93$, $SE = 6.18$; $t2(30) = -3.28$, $SE = 14.86$. (None of the covariate factors were significant.) No significant effect of word frequency was found on the errors, $t1(29) = -.25$, $SE = .008$ and $t2(30) = 1.26$, $SE = .011$.

Discussion of Experiments 1 and 2

The results from Experiments 1 and 2 can be easily summarized. In Experiment 1, the AoA effect on RTs was significant when word frequency was controlled for (though the effect was marginally significant in the by-item analysis), and in Experiment 2 the word frequency effect was significant when AoA was controlled for. On errors, only a significant effect of AoA was observed in the by-participant analysis. These findings replicate previous observations obtained in English and are compatible with an interpretation which locates word frequency at the level of the input visual-orthographic lexicon and AoA at the level of the ouput (phonological) lexicon. As far as French is concerned, the observation of reliable effects of both AoA and word frequency on RTs in the visual lexical decision task is the first that we are aware of, given that previous studies conducted in French on word frequency in lexical decision did not take AoA into account. It should be recalled that the word stimuli used in the current Experiment 2 did not give rise to reliable word frequency effects when these stimuli had to be produced from pictures in either their spoken or in written form (Bonin et al., 2001). In the following experiment, a large set of items was used and multiple regression analyses were performed to assess the robustness of these independent effects in lexical decision, but more importantly, to test for an interaction between word frequency and AoA as reported in English in a full factorial design (Gerhand & Barry, 1999).[3]

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3. In Experiment 3, we used regression analyses rather than a factorial design for the following reasons. First of all, since we wanted to compare our results with those previously obtained on the same word stimuli in picture naming (Bonin et al., in press), the kind of stimuli used (i.e., pictoriable stimuli) led to the problem that it was not possible to match the words on several properties while at the same time retaining a sufficient number of words in each of the cells corresponding to the crossing of word frequency and AoA factors. It should also be noted that because of the important negative relationship between AoA and frequency, factorial experiments using word frequency and AoA are always difficult to design. Second, although it has been claimed that possible interactions between variables can be missed with regression analyses (Gerhand & Barry, 1999), the examination of interactions between variables is indeed possible, and in Experiment 3, the specific interaction between AoA and word frequency was assessed using the procedure specifically proposed by Aiken and West (1991). Third, it has been argued that the multiple regression

EXPERIMENT 3

As stressed by Barry et al. (1997), it is important in multivariate studies to include the most essential variables that might be expected to have an effect on response times. Therefore, the various factors that we considered worth examining included: AoA, word frequency, image variability, conceptual familiarity, bigram frequency, number of orthographic neighbours, number of higher orthographic neighbours, orthographic length (i.e., number of letters) and grapheme-to-phoneme consistency. As in Experiments 1 and 2, the AoA, image variability, and conceptual familiarity scores were taken from Alario and Ferrand (1999), word frequency values from Imbs (1971), number of orthographic neighbours and number of higher orthographic neighbours were obtained from Brulex (Content et al., 1990) and bigram frequency values were selected from Content and Radeau (1988). Finally, grapheme-to-phoneme consistency scores were computed using Véronis' (1988) procedure.

Image variability and conceptual familarity measures were included because of their reliability to index semantic representations. It should be remembered that image variability corresponds to the degree to which words evoke few or many different mental images. It is assumed that words that are rated high on image variability possess richer semantic representations than those that are rated low (Bonin et al., in press;

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approach causes a number of problems such as the possibility of suppressing predictor variables because of their correlations with other variables (Morris, 1981). An implicit claim is therefore that factorial designs should be preferred over regression analyses because the results obtained from the former approach are more secure. This is certainly true when it is possible to match on all the other important potential factors inflencing the dependent variable. However, when, as in the present study, this is not the case, it is necessary to include unmatched factors as covariates in factorial designs (e.g., Berry & Feldman, 1985; Cohen, 1998). Since variance and covariance analyses are only special cases of regression analyses (e.g., Cohen & Cohen, 1983), the problem of suppressing predictor variables because of their correlations with other variables persists. It should also be noted that the reliability of the analysis of variance can sometimes be questionable because of the loss of information due to the break of the contiguity in favour of the opposition of groups of extreme values.

Sanfeliu & Fernandez, 1996). In the word-reading literature, "imageability effects" are generally assumed to signal the involvement of semantics (Cortese, Simpson, & Woolsey, 1997; Plaut & Shallice, 1993; Strain & Herdman, 1999; Strain et al., 1995; van Hell & de Groot, 1998). In the following experiment, we considered image variability instead of imageability because imageability scores were not available for our stimuli. However, these variables are related. As far as imageability is concerned, de Groot (1989) found a small and unreliable effect of imageability on naming latencies (see also, Brown & Watson, 1987; Coltheart et al., 1988, for a lack of an effect of this variable), but Strain et al. (1995) suggested that the effect of imageability on word naming is essentially seen on low-frequency irregular/inconsistent words (see also, Strain & Herdman, 1999). Imageability effects have been reported in lexical decision tasks (Kroll & Merves, 1986; Morrison & Ellis, 2000; van Hell & de Groot, 1998) suggesting that semantic representations are involved in this task.

As far as the number of orthographic neighbours is concerned, there is some evidence that words with a high number of orthographic neighbours are responded to faster than words with fewer orthographic neighbours (e.g., Andrews, 1989, 1992). Concerning the number of higher frequency neighbours, it has been shown that words having higher frequency neighbours are processed slower than words having no higher frequency neighbours (Grainger, 1990; Grainger & Segui, 1990; Grainger, O'Regan, Jacobs, & Segui, 1989). Finally, regarding grapheme-to-phoneme consistency, there is ample evidence for consistency/regularity effects in visual word recognition (e.g., Glushko, 1979; Jared, McRae, & Seidenberg, 1990; Peereman & Content, 1997).

Method

Participants. Thirty-six students from the same pool as in the previous experiments were involved and received course credits. None had participated in any of the previous experiments.

Stimuli. The experimental stimuli included 237 words taken from the Alario and Ferrand (1999) database (see Appendix 3) and 237 nonwords. The statistical characteristics of the word stimuli used in Experiment 3 are shown in Table 4.[4] The nonwords were created in exactly the same way as described for the previous experiments. Twenty stimuli were used as warm-ups.

Table 4
Statistical characteristics of the word stimuli used in Experiment 3

	Mean	*SD*	Min-max
Conceptual familiarity*	3.10	1.21	[1.07-4.97]
Image variability*	2.93	0.67	[1.70-4.70]
AoA*	2.17	0.63	[1.12-4.36]
Word frequency**	44	98	[0-892]
Orthographic length (Nb of letters)	6.29	1.80	[3-12]
Nb of orthographic neighbours	1.84	2.49	[0-14]
Nb of higher orthographic neighbours	0.50	1.07	[0-8]
GP consistency***	72	14	[30-100]
Log bigram frequency****	1176	654	[83-4028]

Notes: * From Alario & Ferrand (1999); ** word frequency per million (from Imbs, 1971); *** using Véronis' procedure; **** from Content & Radeau (1988); Nb = number; GP = grapheme-phoneme.

Apparatus and procedure. These were identical to Experiments 1 and 2. The stimuli were randomly presented to the different participants. The session lasted for about forty minutes. Short breaks were proposed to the participants after about every 100 trials.

4. It should be noted that in order to enable direct comparisons with the subsequent multiple regressions, these characteristics and the correlations given in Table 5 were computed on the 220 items with valid values for all the variables. It should also be noted, however, that the same patterns of characteristics and correlations were observed when the computations were performed separately for each variable or for each pair of variables, using all their non-missing values.

Results

Only correct RTs to words were analysed. Thus, no analysis was performed on the errors. Three word stimuli were discarded from the analyses because they yielded an error rate greater than 50%: "*cor*", "*burin*", and "*mouffette*". For the 234 remaining word stimuli, 3.11% of the trials were removed because of erroneous responses. As in Experiments 1 and 2, RTs for words exceeding two standard deviations above the participant and item means were discarded (2.3%). Overall, 5.41% of the word data were excluded.

Mean RTs to words and standard deviations of these means are provided in Appendix 3.

In all the analyses, objective frequency measures were transformed to log(freq + 1).

Table 5 shows the intercorrelations between the variables. The independent variable that had the highest positive correlation with RTs was AoA, followed by orthographical length. Word frequency, image vari-

Table 5
Significant correlations ($p < .05$) between the variables

	RT	AoA	Freq	Fam	Ivar	Bigram freq	ON	ON+	Ol	GP
AoA	.62									
Freq	-.54	-.53								
Fam	-.33	-.49	.40							
Ivar	-.46	-.61	.53	.59						
Bigram freq	-.15									
ON	-.25	-.18	.17			.16				
ON+							.72			
Ol	.42	.23	-.37				-.54	-.40		
GP										

Notes: AoA = age-of-acquisition; Freq = objective frequency (log); Fam = conceptual familiarity; Ivar = image variability; Bigram freq = bigram frequency; ON = number of orthographic neighbours; ON+ = number of higher frequency orthographic neighbours; Ol = orthographic length (number of letters); GP = grapheme-phoneme consistency.

ability, familiarity, and the number of orthographic neighbours had decreasing negative correlations with RTs. Beyond the classical negative correlation between AoA and word frequency, two clusters of independent variables appeared: (1) word frequency, image variability, and familiarity; (2) the numbers of orthographic neighbours and of higher frequency neighbours. These two variables were also negatively correlated with the orthographic length. The quasi-absence of relations between bigram frequency and GP consistency with all other independent variables and RTs can also be noted.

Multiple regression 1. The overall equation given by the simultaneous regression analysis using all the independent variables was significant, $F(9, 210) = 24.40$, $r^2 = .511$, $p < .001$.

Table 6 shows that the variables that had significant effects were: (1) AoA and orthographic length for which increasing values tended to produce increasing RTs; (2) word frequency and bigram frequency which, by contrast, had a negative impact on RTs.

Table 6
Summary of multiple regression analysis 1

Multiple R			.715	
	β	*SE*	t	*p*
AoA	0.414	0.066	6.256	0.001
Freq	-0.179	0.065	-2.732	0.007
Fam	0.020	0.062	0.317	0.751
Ivar	-0.094	0.070	-1.344	0.180
Bigram freq	-0.108	0.050	-2.137	0.034
ON	0.036	0.080	0.452	0.652
ON+	-0.023	0.074	-0.304	0.761
Ol	0.267	0.064	4.194	0.001
GP	0.024	0.049	0.488	0.626

Notes: AoA = age-of-acquisition; Freq = objective frequency (log); Fam = conceptual familiarity; Ivar = image variability; Bigram freq = bigram frequency; ON = number of orthographic neighbours; ON+ = number of higher frequency orthographic neighbours; Ol = orthographic length (number of letters); GP = grapheme-to-phoneme consistency.

Multiple regression 2. A multiplicative term between AoA and word frequency [log(freq+1)] was introduced in order to examine the interaction between the two variables. All the independent variables were standardized before the formation of the multiplicative term (Aiken & West, 1991). The results are shown in Table 7.

The improvement in the explanatory power resulting from the inclusion of the interaction term was relatively important and significant, $F(10, 209) = 27.28$, $r^2 = .566$, $p < .001$; change in $r^2 = .055$, $p < .001$. More importantly, with the exception of bigram frequency, the same independent variables had significant effects, and furthermore, the interaction term was significant. It should also be noted that the introduction of this term affected the estimations of the effects in a relatively important way, thus indicating the relevance of its inclusion in the equation.

We used the procedure suggested by Aiken and West (1991) to run post-hoc tests of the simple slopes of AoA for low-frequency words, that

Table 7
Summary of multiple regression analysis 2

Multiple R		.752		
	β	*SE*	t	*p*
AoA	0.328	0.065	5.077	0.001
Freq	-0.274	0.064	-4.253	0.001
Fam	0.004	0.059	0.065	0.948
Ivar	-0.088	0.066	-1.340	0.182
Bigram freq	-0.075	0.048	-1.564	0.119
ON	0.019	0.075	0.254	0.799
ON+	-0.014	0.070	-0.194	0.846
Ol	0.258	0.060	4.298	0.001
GP	0.026	0.046	0.568	0.570
AoA * Freq	-0.238	0.046	-5.151	0.001

Notes: AoA = age-of-acquisition; Freq = objective frequency (log); Fam = conceptual familiarity; Ivar = image variability; Bigram freq = bigram frequency; ON = number of orthographic neighbours; ON+ = number of higher frequency orthographic neighbours; Ol = orthographic length (number of letters); GP = grapheme-to-phoneme consistency.

is to say, one standard deviation below the mean for frequency, and high-frequency words, i.e., one standard deviation above the mean for frequency. Technically, for high-frequency words, for example, the tests were performed by repeating the multiple regression using (Frequency - 1) and (Frequency - 1) × AoA instead of Frequency and Frequency × AoA. The same procedure was applied with (Frequency + 1) and (Frequency + 1) × AoA for low-frequency words. A representation of the corresponding slope is shown in Figure 1.[5]

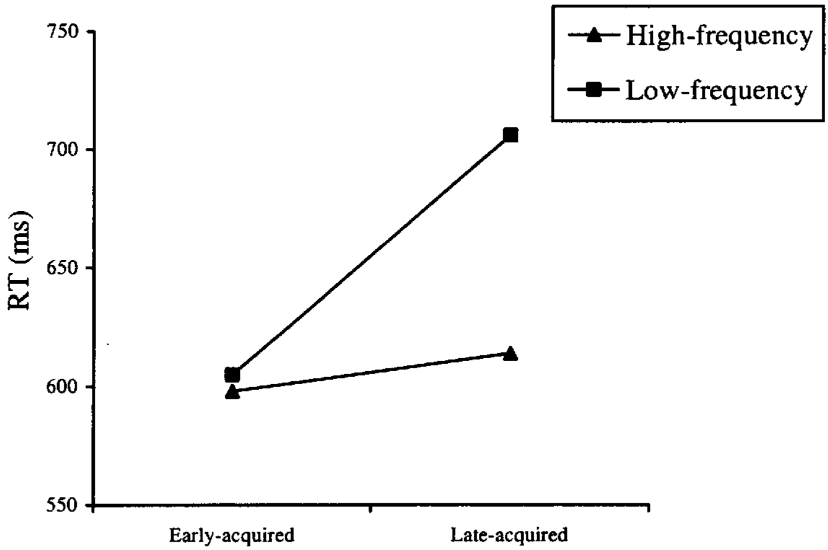

Figure 1. Interaction between AoA and word frequency.
"Early acquired" = 1 standard deviation below the mean of age of acquisition, which corresponds to items with an AoA equal to 1.54 and "Late acquired" = 1 standard deviation above the mean of AoA which corresponds to items with an AoA equal to 2.8. "Low frequency" = 1 standard deviation below the mean of log(freq + 1) which corresponds to frequencies of 2.14 per million and "High frequency" = 1 standard deviation above the mean, which corresponds to frequencies of 60.46 per million.

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5. This representation is given for all the other independent variables fixed to their mean. However, the slopes remain the same irrespective of the values chosen for the variables.

For low-frequency words, the effect of AoA was positive and significant, $\beta = .566$, $t = 8.192$, $p < .001$. For high-frequency words, the effect of AoA was slightly positive but not significant, $\beta = .09$, $t = 1.019$, $p = .31$.

Discussion

The findings obtained from Experiment 3 are straightforward. AoA and word frequency were found to exert reliable independent effects. More importantly, an interaction was found between the two variables with the result that an effect of AoA was observed on low-frequency words but not on high-frequency words. This latter finding is especially important because it shows that the interaction between AoA and word frequency can also be obtained in French. It should be remembered that, as far as we are aware, such an interaction has so far only been reported for the English language. We shall discuss the implications of this finding in the General discussion.

The multiple regression analyses also revealed independent effects of orthographic length and bigram frequency. It should be noted, however, that this latter variable no longer reached significance when the multiplicative term was introduced in the regression analysis. It should also be noted that no reliable word length effect was found in the lexical decision task in Morrison and Ellis' study (2000). Conceptual familiarity and image variability were not found to exert reliable independent effects on RTs. As far as conceptual familiarity is concerned, this result accords with Morrison and Ellis's (2000) lexical decision data. Image variability was introduced in the regression analyses because of its reliability in indexing semantic representations. We did not find a reliable effect of this variable in Experiment 3, contrary to what we had previously found when the same word stimuli were produced from pictures (Bonin et al., in press). We interpret this pattern of findings as suggesting that image variability effects are stronger in picture naming than in lexical decision because the former task necessarily requires the activation of semantic representations whereas the latter task can, at least under certain conditions, be performed without or with little access to meaning. Thus, the absence of a reliable effect of image variability in lexical decision in Experiment 3 does not imply that semantic representations are never made available in this task. Indeed, Morrison and Ellis

(2000) found a reliable effect of imageability in lexical decision in English, which suggests that the meaning of words can be consulted in lexical decision if we accept the common assumption that imageability effects indicate the involvement of semantics. Number of orthographic neighbours had no reliable independent effect on RTs as previously reported in a lexical decision task conducted in English by Morrison and Ellis (2000). The same was found as far as the number of higher frequency orthographic neighbours is concerned. We will not elaborate further on these latter results given that the focus of our study is AoA and word frequency. It must be stressed, however, that studies that have focused on orthographic neighbour effects in visual word recognition have generally yielded inconsistent results and that this issue appears to be somewhat complex (see Andrews, 1997, for a review). Finally, we did not observe a reliable effect of grapheme-to-phoneme consistency in lexical decision. However, it is worth noting that consistency effects are more generally observed in reading aloud than in lexical decision. Moreover, since the set of stimuli included polysyllabic words, it was not possible to include more fine-grained measures of orthography-to-phonology consistency as is generally the case in studies using monosyllabic words (for instance, consistency measures at the body level). We acknowledge therefore that our index of consistency was relatively rough and was consequently insufficiently optimized to reveal consistency effects.

It might be argued that the AoA and word frequency effects observed in Experiments 1 to 3 were indeed "lexical familiarity" (i.e., subjective frequency) effects in disguise. In effect, in the word recognition literature, the lexical familiarity variable has sometimes been argued to be an important variable that should be taken into account (Gernsbacher, 1984; Gordon, 1985). Gernsbacher's (1984) well known study has shown that subjective frequency estimates might help to resolve discrepancies found in some word recognition studies. To address this potential concern, we performed additional analyses taking account of lexical familiarity values. Subjective frequency estimates for the word stimuli used in Experiments 1 to 3 were collected from adults. The participants had to indicate on a 5-point scale how familiar they were with the spoken or written form of each of the words presented in a list. More precisely, the participants were presented with five squares printed in front of each word with the first square corresponding to the response "unknown" and the last one "very frequent". They indicated their choice by putting a cross in the corresponding square. Participants' judgements were converted to numerical values ranging from 1 (unknown) to 5 (very frequent). The analyses have revealed that, as far as Experiments 1 and 2 are concerned, whereas subjective frequency was indeed confounded with AoA in Experiment 1, with early acquired words being significantly rated as more lexically familiar than late acquired words (3.56 versus 2.53), in Experiment 2, the difference between HF and LF words was not significant on subjective frequency ratings (3.69 and 3.34, respectively). When subjective frequency ratings were introduced as a covariate factor in Experiment 1, the pattern of results was the same as previously reported and the covariate was not significant. Turning to Experiment 3, two multiple regression analyses were conducted on the same variables (as described in the Results section of Experiment 3) with the inclusion of subjective frequency estimates as an independent variable: Regression 1 examined independent effects and Regression 2 included the AoA × Word frequency interaction term. The multiple regression analyses have revealed the following: (1) The inclusion of the subjective frequency variable only slightly improves the global explanatory power of the two regressions; (2) AoA, word frequency and orthographic length were still significant in the two regression analyses as were bigram frequency in Regression 1 and the interaction between AoA and word frequency in Regression 2; (3) The estimations of the effects were very similar to those found in the previous regression analyses that did not take subjective frequency estimates into account; (4) Conceptual familiarity was significant in Regression 1 and significant in a one-tailed test in Regression 2; (5) The subjective frequency variable was significant in the two regression analyses. However, it appeared that for the conceptual familiarity and subjective frequency variables a multicolinearity problem occurred: the R-square between conceptual familiarity and the other independent variables was about .80 and that between subjective frequency and the other independent variables was about .85. A regression analysis performed with subjective frequency ratings as the dependent variable and the same predictors used in the previous regression analyses as independent variables revealed that subjective frequency was significantly influenced by conceptual familiarity (β = .685), image variability (β = .195) and AoA (β = -.15). No significant contribution of objective word frequency was found. This latter analysis suggests that: (1) Subjective frequency ratings are not an accurate reflection of true word frequency and, therefore, that the use of subjective frequency estimates as a substitute for objective frequency measures is misleading since several factors influence participants' ratings, and more particularly, conceptual familiarity, image variability and AoA (see also Brown & Watson, 1987, for a similar conclusion); (2) because of its composite nature, including subjective frequency in the regression analyses tends to give unreliable estimations of its effect and also of the other effects (for instance, the conceptual familiarity variable for which the estimations of coefficients that were "strangely" positive in the regression analyses that included subjective frequency estimates).

A final point that deserves a brief comment is why word frequency did not emerge in written and spoken picture naming while simultaneously producing reliable effects in lexical decision (the mean spoken latencies corresponding to the Bonin et al. (2001) study can be seen in Table 2). Indeed, this aspect is intriguing in the light of certain studies conducted on spoken picture naming in English which have revealed significant effects of word frequency in addition to AoA (Barry et al., 1997; Ellis & Morrison, 1998). One reason might be that the objective word frequency measures that we used were not up-to-date frequency measures since studies conducted with large sets of items and *more up-to-date frequency measures* have revealed reliable word frequency effects in picture naming. Fortunately, since Bonin et al.'s (in press) picture naming study, more recent frequency measures for French have been made available (New, Pallier, Ferrand, & Matos, 2001). We have therefore reanalysed the naming data from Bonin et al. (2001) using these more recent frequency counts (referred to as "FastSearch" frequency measures, New et al., in press). The main finding of these analyses was that the interaction term formed by word frequency and AoA was significant (on a one-tailed test) in *written* but not in spoken picture naming. More precisely, we found that the word frequency effect was significant for late-acquired words but not for early-acquired words. It should be noted that the pattern of results found in the lexical decision task in Experiment 3 remained unchanged when FastSearch frequency measures were used. The discrepancy between spoken and written picture naming might be due to the fact that written but not spoken frequency measures were used. However, this latter point is speculative and cannot be answered since, to our knowledge, there is no objective spoken frequency count available for French. Nevertheless, these findings indicate that the interaction between AoA and word frequency in picture naming can, to a certain extent, be observed in a language other than English.

GENERAL DISCUSSION

A series of three experiments was designed to examine the influence of both AoA and word frequency in visual lexical decision using French stimuli. In accordance with the perspective put forward by Gerhand and Barry (1999), we hypothesized that word frequency should have its primary locus in the input visual lexicon whereas AoA should act at the level of the output (phonological) lexicon. This hypothesis led us to predict both AoA and word frequency effects on RTs for words in lexical decision. Indeed, in Experiment 1, we found a reliable AoA effect when objective word frequency was controlled for, and in Experiment 2 we observed a reliable word frequency effect when AoA was controlled for. Based on the finding of an interaction between word frequency and AoA in lexical decision in English (Gerhand & Barry, 1999), a third experiment using a large set of items was performed. Multiple regression analyses conducted on the RTs for words obtained from Experiment 3 revealed both independent effects of AoA and word frequency as well as an interaction between these two variables. The interaction indicated that AoA had a negative effect on low-frequency words and no reliable effect on high-frequency words or, in other words, that an AoA effect was observed on low-frequency but not on high-frequency words. Taken together, these findings are consistent with the hypothesis that word frequency and AoA affect different processing levels in visual word recognition as indexed by the visual decision task.

As claimed in the Introduction, AoA and word frequency effects are robustly found in a large variety of lexical processing tasks but there is, as yet, no unified account for these effects as we shall now briefly summarize.

As far as AoA is concerned, it has been claimed that this variable should affect the output phonological representations with the result that words acquired early in life should be retrieved faster because their phonological representations are holistic in nature whereas those of late acquired words are more fragmented and thus take more time to be assembled ("the phonological completeness hypothesis", Brown & Watson, 1987). This explanation is the most popular explanation of AoA effects in the literature. Other accounts of AoA do exist, however. For instance, AoA has also been considered to be a variable which affects the semantic system on the basis of the findings of strong AoA effects in semantic processing tasks (Brysbaert, Van Wijnendaele, & De Deyne, 2000). Another account is that AoA is encoded in the links relating semantic and phonological representations (Hirsh & Funnell, 1995). Finally, AoA effects might be more widespread than originally thought and there might therefore be more than a single locus underlying AoA effects (Moore & Valentine, 1999).

If we now consider word frequency, it has also been proposed that word frequency is situated at the level of phonological representations (Jescheniak & Levelt, 1994) or in the links relating semantic and phonological representations (Barry et al., 1997). It is clear that some accounts of word frequency and AoA are, to a certain extent, very closely related in that they localize these effects at or around the level of phonological representations. In the light of a growing body of evidence in support of both word frequency and AoA effects in various lexical processing tasks, the challenge facing any model of lexical processing is to account for both effects.

As far as the lexical decision task is concerned, there have been numerous different accounts of word frequency in the literature. For instance, Morton (1969, 1979) localized the frequency effect at the level of word detectors called logogens. Logogens have different thresholds which vary as a function of frequency so that words encountered more frequently have lower thresholds than words encountered less frequently. In McClelland and Rumelhart's (1981) "localist" connectionist model, word frequency is encoded at the level of resting activation nodes with high-frequency words having a higher resting activation level than low-frequency words, whereas in parallel distributed models such as the Seidenberg and McClelland (1989) model, word frequency is encoded in the weights relating different subword representations with the result that the connections to the representations of frequent words are easier to traverse than those to rare words. A somewhat different proposal is that word frequency affects the order search limited to a set of lexical entries derived from the initial perceptual analysis (Forster, 1976). Accordingly, high-frequency word forms should be compared before low-frequency word forms. Finally, Balota and Chumbley (1984) have proposed a familiarity-based decision process that would also account for word frequency effects in lexical decision (see also Morrison

& Ellis, 1995, for a post-access familiarity check account of word frequency in lexical decision).

It should be recalled that the above-mentioned theoretical word recognition frameworks were essentially built to account for word frequency. AoA was not integrated in these frameworks. Though it is difficult to imagine in great detail how all these different accounts of word frequency effects could be modified in a way that might readily account for both AoA and word frequency effects as well as their interaction, as put forward by Brysbaert (1996), most of the models can certainly be adapted in a way that explains both AoA and word frequency effects as well as their interaction (for instance the original search model proposed by Forster (1976) has been modified in a way that accounts for both effects, see Forster, 1992). As far as connectionist models of word recognition are concerned, it has often been claimed that models using backpropagation as a learning rule (e.g., Seidenberg & McClelland, 1989) are not able to account for AoA effects, because they exhibit "catastrophic interference" from newly learned patterns overwriting earlier-learned patterns (Morrison & Ellis, 1995). However, Ellis and Lambon Ralph (2000) have recently shown that connectionist models trained by backpropagation naturally give rise to AoA effects when patterns are introduced at different points in training and when the learning of early and late patterns is cumulative and interleaved. Also, these authors have shown that such models are able to account for both AoA and word frequency. In the type of network used by Ellis and Lambon Ralph (2000), differences in the point of entry of patterns into training (AoA) and differences in the frequency with which patterns are subsequently trained affect the network structure in a similar manner, that is to say, by influencing the extent to which weights change in response to training. According to Ellis and Lambon Ralph (2000), their simulations permit us to make the strong implication that any task that is affected by AoA will also be affected by frequency (or the reverse).

In our study, we have followed the viewpoint advocated by Gerhand and Barry (1999) according to which AoA and word frequency affect two different loci in visual word recognition. In this framework, word frequency affects access to input orthographic representations and AoA affects output *lexical* phonological representations which are consulted in order to make confident lexical decisions, and more particulary, in the case of low-frequency words. Our findings are consistent with such an account. This account is certainly consistent with word recognition models which assume that orthographic lexical codes and both lexical and sublexical phonological codes play a role, as does the DRC model (Coltheart et al., 2000). To date, the DRC model is one of the prominent models of word recognition and reading aloud. Although the DRC model says nothing about AoA effects in word recognition, the fact that the present model distinguishes between an orthographic input lexicon and a phonological output lexicon means these findings do not appear to contradict the DRC model in any fundamental way. We acknowledge, however, that the type of connectionist model used by Ellis and Lambon Ralph (2000) appears to be a good candidate as an account for both AoA and word frequency effects as well as their interaction in the lexical decision task, provided that the model is modified in a specific way that permits the implementation of the task. In effect, lexical decision represents something of a challenge for parallel distributed models because there is no discrete event during processing which signals whether the stimulus is a word or a nonword (Coltheart et al., 2000).

The findings obtained in the present study, which showed clear effects of both word frequency and AoA as well as an interaction between the two variables in lexical decision, together with the findings gathered from our reanalyses of the Bonin et al. (in press) picture naming data reported in the Discussion of Experiment 3, which also provided some indication of an interaction between AoA and word frequency (as well as with the previous report of such an interaction in spoken picture naming in English, Barry et al., 1997), strongly suggest that word frequency and AoA are unlikely to have a single locus. We support the claim put forward by Gerhand and Barry (1999) that word frequency has its primary locus at the level of the visual-orthographic input lexicon. However, such a claim is not incompatible with the idea that word frequency may have a different locus in tasks such as spoken or written picture naming. It is already clear that future research is crucially needed in order to shed light on the somewhat complex issue of the locus(i) of word frequency and AoA.

To conclude, our study makes a valuable contribution in showing that both AoA and word frequency are important factors in visual lexical decision. It also shows that the interaction between word frequency and AoA that was initially reported in English in visual lexical decision can be extended to the French language. Although a unified account of these effects has not as yet been achieved, the present findings together with other findings reported in different languages impose further constraints in the modeling of word recognition that can no longer be ignored by psycholinguists.

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RÉSUMÉ

L'impact de la fréquence objective et de l'âge d'acquisition des mots (AoA) a été étudié au sein de trois expériences de décision lexicale visuelle conduites en français. Dans l'expérience 1, un effet d'AoA a été observé sur les TRs lorsque la fréquence objective des mots était contrôlée et, dans l'expérience 2, un effet de fréquence des mots a été observé sur les TRs lorsque l'AoA était contrôlé. Dans l'expérience 3, un nombre élevé de stimuli a été utilisé et des analyses de régression multiple ont été conduites. Les analyses ont révélé des effets importants et significatifs de l'AoA et de la fréquence des mots ainsi qu'une interaction entre les deux variables, de sorte qu'un effet d'AoA était obtenu sur les mots de basse fréquence seulement, répliquant ainsi une interaction préalablement rapportée en décision lexicale en anglais (Gerhand & Barry, 1999). Les implications de ces résultats sont discutées.

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Appendix 1
List of word stimuli used in Experiment 1 with the mean RTs (RT in ms) and standard deviations of these means (*SD*)

Stimuli	Translation	RT	*SD*
Early acquired words			
Arbre	Tree	548	76
Ballon	Ball	594	85
Canard	Duck	588	115
Carotte	Carrot	586	95
Chaise	Chair	577	100
Chat	Cat	542	69
Chien	Dog	585	198
Cuillère	Spoon	785	164
Doigt	Finger	567	116
Gâteau	Cake	552	62
Lapin	Rabbit	563	114
Lion	Lion	566	111
Manteau	Coat	612	100
Montagne	Mountain	596	115
Parapluie	Umbrella	641	99
Poisson	Fish	584	93
Pomme	Apple	550	81
Vache	Cow	558	125
Late acquired words			
Bureau	Desk	574	87
Cactus	Cactus	668	107
Canon	Cannon	686	177
Cerveau	Brain	581	81
Chemise	Shirt	556	80
Chèvre	Goat	624	109
Cigarette	Cigarette	661	89
Couronne	Crown	717	113
Drapeau	Flag	699	149
Enclume	Anvil	810	125
Fusée	Rocket	583	91
Lampe	Lamp	622	108
Marteau	Hammer	666	132
Pipe	Pipe	641	144
Poignée	Handle	624	117
Prise	Plug	654	128
Tambour	Drum	630	96
Violon	Violin	636	159

Appendix 2
List of word stimuli used in Experiment 2 with the mean RTs (RT in ms) and standard deviations of these means (*SD*)

Stimuli	Translation	RT	*SD*
High-frequency words			
Arbre	Tree	549	79
Boîte	Box	516	81
Chaise	Chair	546	116
Chapeau	Hat	567	143
Cheval	Horse	526	97
Cœur	Heart	553	122
Etoile	Star	562	96
Fenêtre	Window	597	184
Fleur	Flower	531	98
Jambe	Leg	547	85
Lune	Moon	562	121
Maison	House	544	107
Montagne	Mountain	577	92
Nuage	Cloud	600	99
Oiseau	Bird	603	127
Soleil	Sun	553	112
Train	Train	555	132
Low-frequency words			
Abeille	Bee	598	112
Banane	Banana	605	119
Bol	Bowl	605	122
Bouton	Button	603	164
Brosse	Brush	631	146
Carotte	Carrot	576	127
Collier	Necklace	589	98
Coq	Rooster	565	128
Fourchette	Fork	721	130
Fraise	Strawberry	596	154
Gâteau	Cake	567	102
Grenouille	Frog	650	139
Parapluie	Umbrella	672	163
Porte	Door	560	133
Poubelle	Trashcan	622	118
Poupée	Doll	566	114
Souris	Mouse	599	171

Appendix 3
List of word stimuli used in Experiment 3 with the mean RTs (RT in ms) and standard deviations of these means (*SD*) (The three items discarded from the analyses [*burin* - *cor* - *mouffette*] are not reported)

Stimuli	Translation	RT	*SD*
abeille	bee	629	139
accordéon	accordion	679	118
aigle	eagle	628	145
aiguille	needle	659	199
ampoule	light bulb	632	118
ananas	pineapple	636	159
ancre	anchor	737	168
âne	donkey	612	178
araignée	spider	644	129
arbre	tree	583	121
arrosoir	watering can	807	228
artichaut	artichoke	749	228
asperge	asparagus	669	143
autruche	ostrich	743	132
avion	airplane	573	108
bague	ring	600	131
balai	broom	647	130
balançoire	swing	698	188
balle	ball	575	81
ballon	balloon	617	116
banane	banana	582	92
boîte	box	571	139
bol	bowl	643	111
botte	boot	627	167
bougie	candle	600	115
bouilloire	kettle	789	193
bouteille	bottle	583	103
bouton	button	637	205
bras	arm	562	99
brosse	brush	578	87
bureau	desk	572	102
bus	bus	583	119
cacahuète	peanut	704	152
cadenas	lock	829	173
camion	truck	575	103
canapé	couch	590	94
canard	duck	559	125

Stimuli	Translation	RT	*SD*
canon	cannon	631	143
carotte	carrot	582	134
casquette	cap	672	140
casserole	pot	652	130
ceinture	belt	598	131
céleri	celery	860	224
cendrier	ashtray	691	168
cerf	deer	613	114
cerise	cherry	589	121
chaîne	chain	598	126
chaise	chair	568	124
chameau	camel	690	166
champignon	mushroom	665	185
chapeau	hat	598	149
charrette	wagon	765	153
chat	cat	532	121
chaussette	sock	600	149
chaussure	shoe	648	150
chemise	shirt	590	139
chemisier	blouse	606	125
chenille	caterpillar	641	182
cheval	horse	606	146
cheveux	hair	568	104
chèvre	goat	609	169
chien	dog	546	120
chou	cabbage	609	128
cigare	cigar	648	157
cigarette	cigarette	626	110
cintre	hanger	771	152
ciseau	scissors	734	204
citron	lemon	584	123
citrouille	pumpkin	650	148
clé	key	588	125
cloche	bell	570	105
clou	nail	570	114
clown	clown	609	149
cochon	pig	610	118
coeur	heart	593	114
collier	necklace	618	104
commode	dresser	894	168
coq	rooster	589	109

Stimuli	Translation	RT	*SD*
couronne	crown	767	169
couteau	knife	585	108
cravate	tie	611	119
crayon	pencil	565	99
crocodile	crocodile	835	235
cuillère	spoon	698	165
cuisinière	stove	632	158
cygne	swan	685	158
doigt	finger	584	82
drapeau	flag	707	146
échelle	ladder	594	165
écrou	nut	734	221
écureuil	squirrel	691	205
église	church	593	101
éléphant	elephant	636	187
enveloppe	envelope	660	143
escargot	snail	646	149
étoile	star	572	127
fenêtre	window	592	126
feu	traffic light	579	112
feuille	leaf	549	88
flèche	arrow	612	104
fleur	flower	563	111
fourchette	fork	696	132
fourmi	ant	677	154
fraise	strawberry	563	110
frigidaire	refrigerator	1068	255
gant	glove	652	135
gâteau	cake	579	111
gilet	jacket	627	107
girafe	giraffe	607	128
gorille	gorilla	683	145
grange	barn	783	150
grenouille	frog	589	107
guitare	guitar	604	127
hache	axe	752	200
haie	fence	676	109
harpe	harp	680	108
hélicoptère	helicopter	810	228
hibou	owl	739	215
hippocampe	sea horse	1027	334
homard	lobster	738	164

Stimuli	Translation	RT	*SD*
horloge	clock	582	79
interrupteur	light switch	968	328
jambe	leg	611	183
jupe	skirt	598	130
kangourou	kangaroo	794	177
lampe	lamp	627	176
landau	baby carriage	907	318
lapin	rabbit	575	100
léopard	leopard	715	157
lèvres	lips	617	85
lime	nail file	719	116
lion	lion	558	105
lit	bed	562	97
livre	book	633	202
luge	sled	692	170
lune	moon	541	93
lunettes	glasses	602	81
main	hand	571	111
maïs	corn	666	134
maison	house	551	132
manteau	coat	606	146
marteau	hammer	679	158
montagne	mountain	605	101
montre	watch	579	84
moto	motorcycle	595	176
mouche	fly	575	115
moufle	mitten	756	216
moulin	windmill	656	195
mouton	sheep	607	104
nez	nose	551	96
noeud	bow	669	180
nuage	cloud	582	79
oeil	eye	603	126
oignon	onion	626	149
oiseau	bird	572	116
orange	orange	576	132
oreille	ear	587	116
orteil	toe	701	131
ours	bear	581	124
pain	bread	568	112
panier	basket	575	113

Stimuli	Translation	RT	*SD*
pantalon	pants	625	172
paon	peacock	744	162
papillon	butterfly	604	105
parapluie	umbrella	675	184
pastèque	watermelon	703	153
pêche	peach	565	145
peigne	comb	641	168
phoque	seal	744	170
piano	piano	594	125
pichet	pitcher	713	169
pied	foot	527	85
pince	pliers	598	112
pinceau	paintbrush	655	111
pingouin	penguin	744	215
pipe	pipe	641	126
poêle	frying pan	621	127
poignée	doorknob	582	101
poire	pear	593	126
poisson	fish	551	121
poivron	pepper	614	106
pomme	apple	576	141
porte	door	568	105
poubelle	garbage can	593	122
pouce	thumb	592	132
poule	chicken	592	146
poupée	doll	578	114
prise	plug	673	110
puits	well	886	290
raisin	grape	604	105
règle	ruler	641	166
renard	fox	602	132
revolver	gun	741	170
rhinocéros	rhinoceros	968	228
robe	dress	594	119
roue	wheel	560	78
rouet	spinning wheel	829	349
sacoche	pocketbook	889	189
salière	salt shaker	741	149
sandwich	sandwich	790	330
sauterelle	grasshopper	732	160
scarabée	beetle	892	282

Stimuli	Translation	RT	*SD*
scie	saw	669	124
serpent	snake	613	105
sifflet	whistle	641	141
singe	monkey	612	150
soleil	sun	591	162
souris	mouse	568	97
stylo	pen	602	116
table	table	549	74
tabouret	stool	638	140
tambour	drum	607	139
tasse	cup	632	147
téléphone	telephone	594	107
télévision	television	593	125
tigre	tiger	600	100
tomate	tomato	580	105
tonneau	barrel	689	113
tortue	turtle	612	128
toupie	top	704	180
tournevis	screwdriver	723	155
train	train	576	118
trompette	trumpet	663	136
vache	cow	555	101
valise	suitcase	563	90
vase	vase	606	170
vélo	bicycle	550	90
verre	glass	600	122
veste	jacket	579	105
violon	violin	574	108
vis	screw	661	116
voilier	saiboat	722	181
voiture	car	553	123
zèbre	zebra	640	148