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Effects of cumulative frequency, but not of frequency trajectory, in lexical decision times of older adults and patients with Alzheimer's disease

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Abstract

The purpose of this study was to investigate the issue of age-limited learning effects on visual lexical decision in normal and pathological aging, by using words with different frequency trajectories and cumulative frequencies. We selected words that objectively changed in frequency trajectory from an early word count (Thorndike, 1921, 1932; Thorndike & Lorge, 1944) to a later one (Francis & Kucera, 1982; Kucera & Francis, 1967): we used *Dated words*, which changed from high frequency values, in effect during the participants' childhood, to low values, later in development, and *Contemporary words*, which showed the reverse pattern of low frequency values in childhood to high ones later in life. Cumulative frequency for these words was assumed to be greater in Contemporary relative to Dated words, as the frequency values from the later word count (1967/1982) remained similar up until testing time according to a current frequency table (CELEX database; Baayen, Piepenbrock, & Gulikers, 1995). As predicted, when word processing involves consistent mappings, no frequency trajectory effect was found in lexical decision. However, a cumulative frequency effect was observed, reflecting an advantage for Contemporary words in both healthy older adults (Experiment 1) and patients with Alzheimer's disease (Experiment 2). This advantage was found to be modified by education level and vocabulary knowledge in healthy older adults (Experiment 3). These participants also performed a subjective AoA rating of the stimuli, which further confirmed that Dated words were acquired before Contemporary words (Experiment 4). Methodological factors are discussed that may account for the finding of age of acquisition effects in lexical decision and other tasks, under some conditions and not others.

Keywords: Age of acquisition; Word frequency; Lexical decision; Word recognition; Aging; Alzheimer's disease

A great number of studies have reported both frequency and age of acquisition (AoA) effects in various word recognition tasks and populations. Frequency effects in picture naming and lexical decision reveal that young adults are faster and more accurate with high, than with low, frequency words (e.g., Carroll & White, 1973; Forster & Chambers, 1973; Jescheniak & Levelt, 1994; Morrison & Ellis, 2000; Oldfield & Wingfield, 1965). Studies of lexical decision in older adults show that the frequency effect remains unaffected by normal

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aging: Although older participants respond more slowly than young ones, there is essentially no age difference in the size of the frequency effect (e.g., Allen, Madden, Weber, & Groth, 1993; Bowles & Poon, 1981; Tainturier, Tremblay, & Lecours, 1989). Patients with dementia also show frequency effects in their naming performance (e.g., Balota & Ferraro, 1993; Lambon Ralph, Graham, Ellis, & Hodges, 1998). AoA effects are also reported in picture and word naming, as well as in lexical decision. Both young and older participants perform better with words acquired earlier in childhood, than with those acquired later (Baumgaertner & Thompkins, 1998; Butler & Hains, 1979; Carroll & White, 1973; Hodgson & Ellis, 1998; Meschyan & Hernandez, 2002; Morrison & Ellis, 1995, 2000; Morrison, Hirsh, Chappell, & Ellis, 2002; Nagy, Anderson, Schommer, Scott, & Stallman, 1989; Poon & Fozard, 1978; Turner, Valentine, & Ellis, 1998; Whaley, 1978). AoA effects are also reported in the picture and word naming abilities of brain-damaged patients (Ellis, Lum, & Lambon Ralph, 1996; Hirsh & Funnell, 1995; Lambon Ralph et al., 1998; Westmacott, Freedman, Black, Stokes, & Moscovitch, 2004).

In light of this evidence, it is generally accepted that both variables—how often a word is encountered and when it is learned—will influence later word processing. More recent studies aim at understanding how frequency and AoA are related to one another, and what their relative importance is in a particular word processing task. Designing behavioral studies that address these issues, however, has proven to be somewhat of a challenge. One of the reasons is that AoA and word frequency tend to be correlated significantly with each other (early-acquired words are encountered more frequently than late-acquired ones). Several researchers have turned to computational modeling as it affords some advantages over behavioral studies in the laboratory, such as greater control over stimuli (Ellis & Lambon Ralp, 2000; Munro, 1986; Smith, Cottrell, & Anderson, 2001; Zevin & Seidenberg, 2002).

Zevin and Seidenberg (2002) have used a model that simulates single-word reading (Harm & Seindenberg, 1999) to specify the conditions under which AoA and frequency effects occur. This model takes into consideration the effects of similarities across the different sets of words presented to the network. When they presented the model with early- and late-acquired sets of words that exhibited consistent spelling–sound mappings (Simulations 1, 2, and 4), Zevin and Seidenberg found an advantage for the early presented set, at the beginning of the training session. They attributed this initial AoA effect to *cumulative frequency*, in light of the fact that the early-acquired words had been presented more frequently than the late-acquired ones, simply because they had a head start by being presented first. Importantly, however, this initial advantage for the early presented items vanished at the end of the training session, when cumulative frequency of presentation was equated between both sets. This suggested that the network had learned the common structures across English orthography and phonology, overriding the advantage of greater initial frequency. Zevin and Seidenberg provided evidence for this assumption in Simulation 3: when the model was shown early and late sets of words with minimal overlap between their respective orthographical and phonological structures, a pervasive AoA effect was found, even after equating for number of occurrences.

Zevin and Seidenberg (2002) concluded that, when cumulative frequency is controlled (all other things being equal), AoA effects depend on the type of mappings involved in the word processing task. In tasks where mappings are consistent, such as for orthography onto phonology of regular English words, minimal or no AoA effects are expected. In such cases, knowledge about mappings may be applied to later word learning, which then attenuates the advantage of early-acquired words. Conversely, in tasks involving arbitrary mappings, such as semantically mediated tasks or use of exception words, knowledge of prior mappings cannot be generalized to subsequent mappings and, therefore, the advantage of early-acquired words over late-acquired ones remains.

AoA effects are thus predicted to be most important in tasks such as picture naming, relative to other tasks, such as word naming. Lambon Ralph and Ehsan (in press) directly tested this prediction both in a computational modeling and a behavioral study. They first looked at the effects of AoA in simulations where mappings were more or less arbitrary, to simulate picture and word naming. As expected, the results showed greater AoA effects in simulations involving more arbitrary mappings than lesser ones. In a following behavioral experiment, they compared performance on a picture and a word naming task by using the same words. Results showed a significant AoA effect only for picture naming.

The view that AoA effects depend on the nature of the word processing task is supported by recent studies and provides a unified account of word recognition. However, previous studies have reported AoA effects in word naming tasks, where mappings between representations are assumed to be consistent (e.g., Gerhand & Barry, 1998, 1999; Monaghan & Ellis, 2002; Morrison & Ellis, 1995; Turner et al., 1998). This has lead Zevin and Seidenberg (2002) to question the methodology used in these studies. In their critical review, they examined the frequency count of the stimuli used in these studies across different databases. They found that the early-acquired words were significantly more frequent than the late-acquired ones. Additionally, they noted that most frequency measures used in these studies did not reflect cumulative frequency, i.e., how many times a word has been encountered during a person's entire lifetime, including childhood. The corpora used in most AoA studies (e.g., Kucera & Francis, 1967) do not include children's reading materials. Thus, the effect of frequency early in life is not captured in these adult frequency norms. Zevin and Seidenberg argued that the AoA effect observed in some reading studies may simply be the expression of early frequency, covertly included in AoA ratings. In favor of this view, Zevin and Seidenberg found a negative correlation between rated AoA and grade-level frequency, which gradually declined with age: the strongest correlation was for grade one level, while the weakest one was for college level.

Zevin and Seidenberg (2002) suggested using cumulative frequency and *frequency trajectory* to address the issue of age-limited learning effects in later word processing. "Frequency trajectory" refers to frequency of occurrence as it is distributed over a lifetime. Thus, some words may have a high frequency of occurrence early in childhood, but a low one in adulthood, whereas other words may show the reverse, giving them different frequency trajectories, but perhaps similar cumulative frequencies. Based on the well-established effect of frequency on word acquisition, words encountered more frequently early in life are acquired before words frequently encountered later in life. Hence, the notion of frequency trajectory is highly relevant to the issue of AoA, and has been shown to predict both subjective and objective AoA measures (Bonin, Barry, Méot, & Chalard, 2004). As pointed out by Zevin and Seidenberg, the concepts of frequency trajectory and cumulative frequency circumvent the circularity problem that arises when using a performance measure, such as AoA, to predict performance on another task. Importantly, both frequency trajectory and cumulative frequency may be derived from objective frequency tables and provide a parsimonious explanation as to why some words are acquired earlier than others.

The notion of frequency trajectory is also relevant to aging and the organization of the mental lexicon across time, since older adults are exposed to changes in the frequency of usage of some words. Indeed, words that older adults frequently used during their childhood may have become outdated, while new words are introduced and become used more frequently later in their adult life. We can track these fluctuations in frequency distribution by using different frequency tables which cover the developmental continuum from childhood to late adulthood, and examine age-limited learning effects on word recognition in older adults. It is also clinically and theoretically relevant to determine whether frequency trajectory or cumulative frequency affords greater resistance to pathology, in diseases such as dementia of the Alzheimer's type (DAT), where loss of semantic memory is a prominent symptom.

The goal of this study was to use the concepts of frequency trajectory and cumulative frequency in a behavioral study, to examine age-limited learning effects on word recognition in healthy older adults and patients with DAT. Only a few studies have manipulated these variables, and none of them involved older adults. Bonin et al. (2004), using regression analyses, looked at which factors predicted performance, in a French word naming and a visual lexical decision task. As expected when the task involves consistent mappings, as it does in French, results indicated no effect from frequency trajectory in the word naming task. However, they did observe a frequency trajectory effect in their lexical decision task, in addition to the predicted effect of cumulative frequency.

A couple of other studies have also reported frequency trajectory effects in both visual lexical decision and word naming tasks (Ghyselinck, Lewis, & Brysbaert, 2004; Stadthagen-Gonzalez, Bowers, & Damian, 2004). These recent findings are at odds with predictions made on the basis of the type of mappings required in these tasks: although Zevin and Seidenberg (2002) did not test visual lexical decision in their modeling study—and acknowledge that important differences exist between lexical decision and word naming tasks— they predicted the absence of age-limited learning effects in this task as in word reading, since they both involve consistent mappings between orthographical and phonological representations.

In light of these discrepant results, we elected to use a visual lexical decision task to examine the influence of frequency trajectory and cumulative frequency in young, healthy older adults, and DAT patients. Additionally, lexical decision can be performed easily by clinical populations, such as DAT patients. We also thought it was essential to use a factorial design and control for a number of lexical properties, because statistical and methodological factors may have influenced previous results. To assess the effect of frequency trajectory on lexical decision, we used words that naturally changed in frequency from an early word count (Thorndike, 1921, 1932; Thorndike & Lorge, 1944) to a later one (Francis & Kucera, 1982; Kucera & Francis, 1967). Four types of words were used: (1) "Dated," with high frequency values in the early word count, and low frequency in the late one; (2) "Contemporary," with high frequency in the late table, and low frequency in the early one; (3) "Popular," with high frequency values in the early and late word counts; and (4) "Rare," with low frequency in the early and late tables. Although it is virtually impossible to pinpoint exactly when the frequency for Contemporary words shifted from low to high between the early and late word counts—and vice versa for Dated words—we can make the assumption, based on the mean age of our participants (born approximately in 1925), that the early values indicate frequency for words in use during the older adult's entire childhood, whereas the later values reflect frequency for words in use during adulthood. It is noteworthy that the early frequency table we used (1921/1932/1944) includes words frequently and widely found in the reading materials of *children and young adults at that time*. This point is central to the notion of cumulative frequency, which must reflect word occurrence throughout the entire developmental continuum.

In that respect, we initially hoped to equate cumulative frequency between Dated and Contemporary words (as we had crossed their frequencies on the early- and late-word counts). However, as cumulative frequency should cover the entire lifetime, we had to consider occurrences of the stimuli up until testing time (i.e., after 1967/1982). We thus measured the frequency of our stimuli against the most current word count we could find, the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995). Although some individual values had changed, the overall pattern of frequency obtained from the late table (1967/1982) was found to be similar to the more current one (1995). The cumulative frequency for Contemporary words was thus assumed to be greater than the one for Dated words, since the latest frequency values (Baayen et al., 1995; Francis & Kucera, 1982; Kucera & Francis, 1967) prevailed for basically all of the older participants' adulthood (approximately age 25–70).

Predictions were based on the assumption that lexical decision involves consistent mappings between orthography and phonology, as suggested by Zevin and Seidenberg (2002). Therefore, no frequency trajectory effect was expected—in which case the Dated words would have been favored—but rather a cumulative frequency effect was predicted. This effect should translate into an advantage in the lexical decision times of Contemporary words relative to Dated words, in both older adults and patients, as well as in young participants (since they were not as exposed to the Dated words as the older adults). We also expected Popular and Rare words to lead to the best and worst performances, respectively, based on the well established effects of word frequency on a range of lexical tasks.

Experiment 1

Method

Participants

In this first experiment, 15 older adults (10 women) were compared to 15 young adults (12 women). All participants were right-handed and native English speakers (see Table 1 for demographic information). General vocabulary level in English was assessed with the Mill Hill Vocabulary Test (Raven, 1965). No significant differences were found between older and young adults on education [$t(28) = 0.860$, $p = .397$] and vocabulary levels [$t(28) = 0.909$, $p = .371$].

Table 1
Demographic information for each group of participants

Group	Demographic information		
	Age	Education level	Vocabulary level
Young			
M (*SD*)	23.27 (1.87)	15.53 (1.13)	77.33 (4.95)
Range	21–28	14–19	70–85
Old			
M (*SD*)	72.93 (3.51)	15.13 (1.41)	75.33 (6.93)
Range	67–78	12–17	70–95
DAT			
M (*SD*)	74.91 (10.35)	14.30 (4.27)	72.50 (11.37)
Range	53–84	7–20	55–95
More educated old			
M (*SD*)	72.73 (3.84)	17.20 (2.27)	90.00 (7.31)
Range	64–78	14–22	75–100

Note. Age and Education level are given in number of years; Vocabulary level is given in percentage.

Materials

Four types of words were used in this study (see Appendix). Two of these word-types, Dated and Contemporary, vary in frequency between the Thorndike-Lorge word count in 1921/1932/1944 (early word count) and the Kucera-Francis count in 1967 and 1982 (late word count). The frequency for Dated words (e.g., *bayonet*), changed from high in the early word count to low in the late one, whereas Contemporary words (e.g., *vehicle*) were low in the early and became high on the late word count. The other two types of words, Popular (e.g., *oxygen*) and Rare (e.g., *amulet*), remained relatively stable over these two word counts (respectively, always high and always low frequency), and essentially served as control conditions for the Dated and Contemporary conditions.

For each of the four word-types, a set of 30 words was selected. Words from the four sets were matched on number of syllables, letters, phonemes, and bigram frequency (available for words under nine letters; Mayzner & Tresselt, 1965). Frequency for all of the stimuli was also derived from a more current count (CELEX: Baayen et al., 1995), so that cumulative frequency covered the entire age continuum. The pattern of frequency found between the different word-types was similar to that of Kucera and Francis (1967; Francis & Kucera, 1982): Current frequency values were lowest for Dated and Rare words, and highest for Contemporary and Popular words (Table 2).

For each word-type, a new set of 30 words was chosen, which roughly shared the lexical properties of the experimental words in terms of frequency, number of

Table 2
Values on the different frequency tables and lexical properties for each word-type

Property	Word-type			
	Contemporary	Dated	Popular	Rare
T-L	5.63	48.57	53.13	5.07
K-F	49.80	4.37	53.40	4.50
CELEX	19.48	4.27	26.90	2.14
SYL	2.9	3	3	3
LET	8.1	8.2	8.1	8.1
PHON	7.3	7.1	7.3	7.4
BIGRAM	158.43	153.88	190.58	105.05

Note. T-L, Thorndike and Lorge (1944; Thorndike, 1921, 1932); K-F, Kucera and Francis (1967; Francis & Kucera, 1982); CELEX database (Baayen et al., 1995); SYL, number of syllables; LET, number of letters; PHON, number of phonemes, BIGRAM, bigram frequency (Mayzner and Tresselt, 1965). Frequency values represent words per million.

syllables, letters, phonemes, and bigram frequency. From this new set, 30 pseudo-words were created by changing one or two letters, making them very word-like.

Procedure

A total of 240 stimuli were presented in two blocks, with an equal number of words and pseudo-words in each one. The order of presentation of the blocks was counterbalanced across participants to minimize fatigue or practice effects for a particular subset of words. Stimuli were presented individually in the center of a computer screen using lowercase letters. Each item remained in view until the participant responded by pressing either the YES or NO key, located on the right side of the keyboard. Participants were instructed to respond as quickly and as accurately as possible, as to whether the item presented was a word (YES button) or not (NO button). Each stimulus presentation was preceded by a cue (*) in the center of the screen which was displayed for 500 ms and replaced by the stimulus without delay. The order of the stimuli within each block was varied semi-randomly: A maximum of three words or pseudo-words, and two words of the same type could be presented in succession. In order to familiarize participants with the task prior to the experimental phase, they received a practice trial with 40 items (20 words and 20 pseudo-words), which were not used in the experimental phase but had similar characteristics as the experimental items.

Results

In this, and the next two experiments, the mean reaction times (RTs) for the correct responses, and the mean percentage of errors for the different word-types were compared in each group of participants. In all experiments, the RT trials of a particular participant were excluded from the analyses if they exceeded by 2.5 standard deviations this participant's mean RTs for the other words in the same category. In all the statistical analyses, when the sphericity assumption was not met, the Greenhouse-Geisser correction was used. All the post hoc analyses were performed with a Tukey *a* test ($p < .05$).

Reaction times

As Fig. 1 shows, older adults generally responded more slowly than young adults. In both groups, RTs to Popular and Rare words were the shortest and longest respectively, the other types of words falling in between, with an advantage for Contemporary over Dated words. This impression was confirmed by a 2 (Age: Old and Young) × 4 (Word-type: Contemporary, Dated, Popular, and Rare) analysis of variance (ANOVA). There were significant main effects of Age [$F(1,28) = 15.78$, $MSE = 130610.95$, $p < .001$], and of Word-type [$F(3,84) = 36.50$, $MSE = 8092.96$, $p < .001$]. The interaction between Age and Word-type did not approach significance [$F(3,84) < 1$, $MSE = 8092.96$, $p = .746$]. A power analysis of the interaction indicated a power level of 0.13; to reach a power level of .80, a total of 270 participants would have been required (Cohen, 1988). A post hoc analysis of the main effect of Word-type revealed that, although the difference between Popular and Contemporary words failed to reach significance, Contemporary words were recognized faster than Dated words, and Dated words were recognized faster than Rare words in both groups. Summary statistics for this and the next two experiments are provided in Table 3.

An additional analysis was conducted by excluding performance with Popular and Rare words. As previously mentioned, these two word-types essentially served as control conditions; they are not central to the issue of frequency trajectory and cumulative frequency effects, and they introduce a lot of variability to the overall

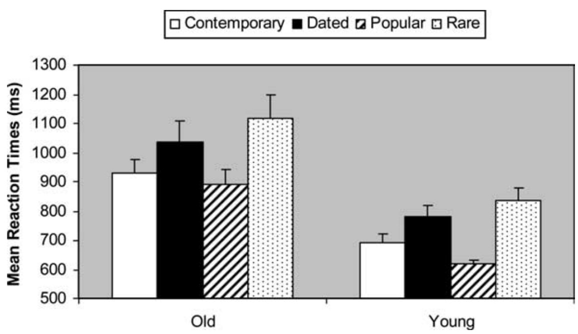

Fig. 1. Mean reaction times (in ms) for the different word-types by healthy older and young adults. Bars represent standard error.

Table 3
Mean reaction times (in ms) on the different word-types for each group of participants

Group	Word-type			
	Contemporary	Dated	Popular	Rare
Old	927.97	1035.99	891.53	1118.29
(*SD*)	(188.15)	(284.28)	(190.10)	(299.76)
Young	691.86	781.23	617.60	834.71
(*SD*)	(113.82)	(141.68)	(55.04)	(177.51)
DAT	1877.19	2066.24	1604.47	2261.97
(*SD*)	(668.53)	(892.97)	(576.76)	(982.43)
More educated old	897.12	906.01	816.13	971.64
(*SD*)	(147.27)	(160.67)	(113.51)	(165.20)

data, especially in the case of Rare words. A 2 (Age: Old and Young) × 2 (Word-type: Contemporary and Dated) ANOVA was thus conducted, which revealed again main effects of Age [$F(1,28) = 12.90$, $MSE = 70024.04$, $p < .001$], and of Word-type [$F(1,28) = 31.77$, $MSE = 4599.70$, $p < .001$]. As with the more general ANOVA presented above, the interaction between Age and Word-type was not significant [$F(1,28) < 1$, $MSE = 4599.70$, $p = .599$]. This more specific analysis further confirmed the advantage in recognizing Contemporary over Dated words in both groups of participants.

Errors

As seen in Table 4, young and older adults produced a generally similar pattern of errors across the different word-types, which closely matched RT performance on these words. The mean percentage of errors made with the different word-types was analyzed with a 2 (Age: Old and Young) × 4 (Word-type: Contemporary, Dated, Popular, and Rare) ANOVA. There were significant main effects of Age [$F(1,28) = 19.89$, $MSE = 127.37$, $p < .001$], indicating that older participants generally made more errors than younger adults in recognizing the words; and of Word-type [$F(3,84) = 67.16$, $MSE = 46.64$, $p < .001$]. The Age by Word-type interaction [$F(3,84) = 15.63$, $MSE = 46.64$, $p < .001$] was also significant. A post hoc analysis of the interaction revealed that, for the young adults, Popular and Contemporary words led to similar percentages of errors. However, Contemporary words produced significantly fewer errors than Dated words, which in turn produced fewer errors than Rare words. For the older adults, differences in percentage of errors were only found to be significant between Dated and Rare words. Thus, no significant differences were found between Popular and Contemporary words, and importantly, between Contemporary and Dated words in the older adults.

Table 4
Percentage of errors on the different word-types for each group of participants

Group	Word-type			
	Contemporary	Dated	Popular	Rare
Young	6.24	17.70	1.15	35.11
Old	2.47	4.75	2.24	13.99
DAT	7.97	10.34	2.16	27.58
More educated old	2.15	3.91	0.92	6.67

Discussion

In this first experiment, as expected, young adults were slower and made more errors with Dated than with Contemporary words, reflecting a reduced familiarity with the former items. Interestingly, older healthy adults were also slower at recognizing Dated than Contemporary words, but unlike young adults, their percentage of errors was similar for both word-types. The absence of a frequency trajectory effect suggests that our lexical decision task involved consistent mappings between representations, which allowed one to counter the initial advantage of early-acquisition, as suggested by Zevin and Seidenberg (2002). The advantage observed for Contemporary words over Dated ones in the RTs of the older adults is thus attributed to cumulative frequency. This interpretation can also account for the absence of a difference in accuracy between Contemporary and Dated words in older adults, but not in young ones: young adults were much less exposed to the Dated words than older adults.

In light of the discrepant results reported in the literature regarding lexical decision tasks, we thought it was necessary to replicate our findings using a different approach. In the next experiment, we tested patients with DAT, a degenerative disease known to affect word knowledge in semantic memory (e.g., Hodges & Patterson, 1995; Martin, 1992). AoA effects have been reported in picture and word naming in DAT patients (Hirsh & Funnell, 1995; Westmacott et al., 2004). In Westmacott et al.' study, patients showed a greater loss of knowledge on a reading task for words which entered the language recently, such as "homophobia," over words, such as "hep-cat," which entered the language longer ago. This temporally graded semantic memory loss in DAT patients suggest that early-acquired words may be more resistant to the effects of pathological aging than late-acquired ones. This "resistance" may be explained in terms of AoA or frequency trajectory and, therefore, should be tested in the context of a lexical decision task. However, empirical data also indicate that frequency effects are present in early DAT patients. In light of this and of our findings from Experiment 1, we expected cumulative frequency to remain as influential in determining lexical decision performance in DAT patients, as in healthy older adults. We thus predicted that Contemporary words would retain their advantage over Dated words in this population, assuming that lexical decision involves consistent mappings between linguistic representations. The next experiment was designed to test this prediction.

Experiment 2

In this second experiment, performance on the visual lexical decision task by the group of healthy older adults from Experiment 1 was compared to that of a group of patients with DAT, matched for age, education, and vocabulary.

Method

Participants

Eleven patients (5 women) with possible or probable DAT were selected for this second experiment (see Table 1 for demographic information). Patients were diagnosed according to the NINCDS-ADRDA criteria (McKhann et al., 1984) by an experienced neurologist at the Baycrest Centre for Geriatric Care. All patients were mildly to moderately impaired according to the clinical evaluation and to the score on the Mini Mental State Examination (score of 18/30 or greater on the MMSE; Folstein, Folstein, & McHugh, 1975). Exclusion criteria consisted of a history of other neurological disease, psychiatric disorder, or general anaesthesia in the past year. All participants had normal or corrected-to-normal vision and were right-handed. All but one patient were native English speakers (the exception having arrived in Canada from Poland at the age of 28 years but had learned English as a child). No differences were found between the healthy older adults and patients with DAT in age [$t(24) = 0.691$, $p = .496$], education [$t(23) = 0.707$, $p = .487$], and vocabulary [$t(23) = .777$, $p = .445$], the latter suggesting that the patients' word knowledge was relatively preserved in this early stage of the disease.

Materials and procedure

The same visual lexical decision task was used as in Experiment 1. The task involved recognition of four word-types: Dated, Contemporary, Popular, and Rare. The procedure was identical to that in Experiment 1, and involved deciding whether the presented stimulus was a word or not. Responses were made by pressing a YES/NO key.

Results

Reaction times

As seen in Fig. 2, DAT patients were generally slower than healthy older adults in recognizing words. In both groups, RTs to Popular and Rare words were the shortest and longest, respectively; RTs to the other types of words fell in between, with shorter RTs for Contemporary compared to Dated words.

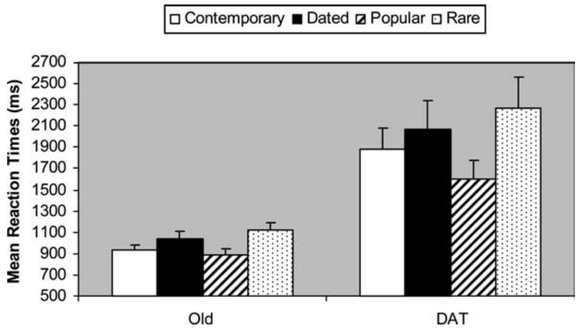

Fig. 2. Mean reaction times (in ms) for the different word-types by healthy older adults and patients with dementia of the Alzheimer's type. Bars represent standard error.

This impression was confirmed by a 2 (Group: Old and DAT) × 4 (Word-type: Contemporary, Dated, Popular, and Rare) ANOVA for correct responses. Both subject(s) and item (i) analyses were provided here.[1] There were significant main effects of Group [$Fs(1,24) = 21.49$, $MSE = 1086533.02$, $p < .001$; $Fi(1,103) = 863.07$, $MSE = 53987.03$, $p < .001$]; and of Word-type [$Fs(3,72) = 24.24$, $MSE = 37994.50$, $p < .001$; $Fi(3,103) = 19.05$, $MSE = 98050.74$, $p < .001$]. The Group × Word-type interaction was also significant [$Fs(3,72) = 5.56$, $MSE = 37994.50$, $p < .05$; $Fi(3,103) = 9.24$, $MSE = 53987.03$, $p < .001$] (see Table 3 for summary statistics).

A more specific 2 (Group: Old and DAT) × 2 (Word-type: Contemporary and Dated) ANOVA was conducted and revealed again, main effects of Group [$Fs(1,24) = 21.94$, $MSE = 566806.54$, $p < .001$; $Fi(1,52) = 505.48$, $MSE = 48699.00$, $p < .001$]; and of Word-type [$Fs(1,24) = 14.39$, $MSE = 19454.80$, $p < .001$; $Fi(1,52) = 3.95$, $MSE = 81244.50$, $p = .05$], clearly indicating that Contemporary words were recognized faster than Dated words. However, contrary to the general ANOVA presented above, the interaction between Group and Word-type was not significant [$Fs(1,24) = 1.07$, $MSE = 19454.80$, $p = .311$; $Fi(1,52) < 1$], thus revealing a similar advantage for Contemporary over Dated words, in both DAT patients and healthy older adults.

[1] Unfortunately, for a few young participants in Experiment 1 and older participants in Experiment 3, we were not able to match the stimuli to the RTs, due to a change in testing personnel. However, we have included the item analyses for the stimuli that were available.

Errors

The percentage of errors made on the different word-types was analyzed and revealed an identical pattern as the one observed for the RTs in both groups of participants (Table 4). These findings were based on a 2 (Group: Old and DAT) × 4 (Word-type: Contemporary, Dated, Popular, and Rare) ANOVA, which showed significant main effects of Group [$F(1,24) = 6.73$, $MSE = 142.74$, $p < .05$], indicating that patients with DAT generally made more errors than healthy older adults in recognizing the different words; and of Word-type [$F(3,72) = 39.15$, $MSE = 43.54$, $p < .001$]. The Group by Word-type interaction also reached significance [$F(3,72) = 4.61$, $MSE = 43.54$, $p < .05$]. For DAT patients, a post-hoc analysis of the interaction revealed no difference between Popular and Contemporary words, and no difference between Contemporary and Dated words. However, DAT patients produced significantly fewer errors with Dated words than with Rare words. An identical pattern of differences was found for the healthy older adults. Hence, the Group by Word-type interaction appears to be stemming from the larger difference between Dated and Rare words in DAT patients relative to healthy older adults, not between Dated and Contemporary words.

Discussion

In this second experiment, which included DAT patients, again we found no evidence for a frequency trajectory effect in visual lexical decision, using either a general or a more specific ANOVA. The general ANOVA, which included all of the different word-types, indicated similar RTs and accuracy for Dated and Contemporary words in patients. More convincingly, however, when the variability introduced by the control words was excluded from the analysis ($SD = 546.40$ ms for Rare words in DAT patients), the Group by Word-type interaction was no longer significant, showing again that frequency trajectory had no effect on patients or on healthy older adults. Rather, both groups recognized Contemporary words faster than Dated words, a result that is attributed to the effect of cumulative frequency.

Overall, the findings from both Experiments 1 and 2 are consistent with the view that, in tasks assumed to involve consistent mappings, there is no age-limited learning effect, and cumulative frequency becomes the major determinant of performance (all other things being equal). In line with this view, we expected experiential factors that may affect word frequency over a lifetime (e.g., educational background), also to have an important influence on lexical decision. Experiential factors vary from one individual to another but may be reflected in scores measuring vocabulary. For example, some words may be used regularly by more educated individuals, while these same words may never be part of the vocabulary of less educated people.

Studies manipulating experiential factors, such as educational background or occupational status, have shown that they can influence the frequency effect (Gardner, Rothkopf, Lapan, & Lafferty, 1987; Stadthagen-Gonzalez et al., 2004; Tainturier, Tremblay, & Lecours, 1992). In their study, Tainturier et al. compared performance of participants with high levels of education to those with low levels of education, on a visual lexical decision task involving recognition of high versus low frequency words. They also looked at whether educational level would differentially affect young and older adults. Results showed that the frequency effect was greater in people with lower education than in those with higher education. Furthermore, the effect of educational level on the frequency effect was found to be independent of aging.

Experiment 3

The results from our two previous experiments showed that performance is driven primarily by cumulative frequency. In order to assess the effects of factors known to influence cumulative frequency, in this next experiment we compared two groups of older adults with the same age but with different vocabulary and educational levels, on our visual lexical decision task. As already mentioned, smaller frequency effects have been reported in people with higher education and better vocabulary than in those with less education and worse vocabulary. These findings suggest a better access to less frequently used words (such as our Dated and Rare words) in more educated individuals than others. Importantly, differences in education and vocabulary levels in people born during the same time period, do not change the age at which frequently used words during childhood (Dated words) are acquired. We thus predicted that performance would not be influenced by frequency trajectory, but that the advantage for Contemporary over Dated words would be reduced in more knowledgeable older adults. This prediction was based on the assumption that more educated individuals would have better access to the currently less frequently used Dated words than less educated people.

Performance by our original group of healthy older adults from Experiments 1 and 2 was compared to that of a new aged-matched group of healthy older adults with more education and better vocabulary (the *More Educated* Old Group).

Method

Participants

In this experiment, the healthy older adults from Experiments 1 and 2 were compared to 15 (9 women) more educated healthy older adults (see Table 1 for demographic information). All participants were right-handed and native English speakers. The two groups did not differ significantly in age [$t(28) = 0.15$, $p = .883$], however, the differences on education [$t(28) = 2.99$, $p < .01$], and vocabulary levels [$t(28) = 5.63$, $p < .001$] were significant, as intended.

Materials and procedure

The same visual lexical decision task as in Experiments 1 and 2 was used. The procedure was identical to that in Experiments 1 and 2, and involved deciding whether the presented stimulus was a word or not by pressing a YES/NO key.

Results

Reaction times

As seen in Fig. 3, the overall speed at which different words were recognized was similar in the two groups. RTs to Popular and Rare words were the shortest and longest, respectively, the other types falling in between for both groups. As previously reported, the Old Group displayed shorter RTs for Contemporary words compared to Dated ones. However, the advantage for Contemporary over Dated words vanished in the More Educated Old Group.

This impression was confirmed by a 2 (Group: Old and More Educated Old) × 4 (Word-type: Contemporary, Dated, Popular, and Rare) ANOVA comparing the mean RTs for correct responses. The main effect of Group was not significant [$F(1,28) = 1.90$, $MSE = 144260.29$, $p = .178$], indicating that RTs for the two groups of older participants were generally similar. A power analysis of the group effect indicated a power level of 0.27; to reach a power level of .80, a total of 128 participants would have been required (Cohen, 1988). However, the main effect of Word-type, and the Group by Word-type interaction were both significant [$F(3,84) = 29.05$, $MSE = 6895.15$, $p < .001$; $F(3,84) = 3.04$, $MSE = 6895.15$, $p < .05$, respectively]. A post hoc analysis of the interaction revealed that for the More Educated Old Group, Popular words were recognized faster than Contemporary words (see Table 3 for summary statistics). Most importantly, however, the difference between Contemporary and Dated words failed to reach significance, as did the difference between Dated and Rare words. This contrasts with the performance by the Old Group in which Contemporary words were recognized significantly faster than Dated words, as previously reported.

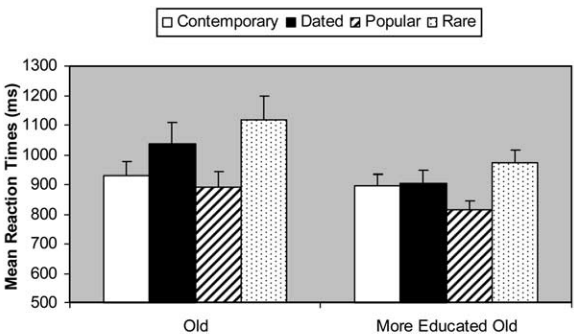

Fig. 3. Mean reaction times (in ms) for the different word-types by healthy older adults and more educated older adults with better vocabulary. Bars represent standard error.

A more specific 2 (Group: Old and More Educated Old) × 2 (Word-type: Contemporary and Dated) ANOVA was also conducted. Again, it indicated no main effect of Group [$F(1,28) = 1.25$, $MSE = 77347.77$, $p = .272$], but the main effect of Word-type [$F(1,28) = 11.36$, $MSE = 4513.85$, $p < .01$] and the interaction between Group and Word-type [$F(1,28) = 8.16$, $MSE = 4513.85$, $p < .01$] remained significant. As can be seen from Fig. 3, the interaction arises because the More Educated Old Group, unlike the Old one, did not favour Contemporary over Dated words (and appear faster at recognizing Rare words).

Errors

A generally similar pattern of errors across the four word-types was found for both groups of healthy older adults (Table 4). A 2 (Group: Old and More Educated Old) × 4 (Word-type: Contemporary, Dated, Popular, and Rare) ANOVA was performed to compare the mean number of errors made with the different word-types. The main effect of Group was not significant [$F(1,28) = 2.79$, $MSE = 64.51$, $p = .106$], indicating that the two groups of older participants generally made the same percentage of errors. The main effect of Word-type was significant [$F(3,84) = 19.09$, $MSE = 24.75$, $p < .001$], as was the Group by Word-type interaction [$F(3,84) = 3.25$, $MSE = 24.75$, $p < .05$]. A post hoc analysis of the interaction revealed no difference between Popular and Contemporary words, and importantly, no difference between Contemporary and Dated words, nor between Dated and Rare words in the more educated older adults. Hence, the Group × Word-type interaction appears to be stemming from the larger percentage of errors for Rare words in the Old Group relative to the More Educated one.

Discussion

This experiment revealed similar lexical decision times for Dated and Contemporary words in a group of more educated and knowledgeable older adults, thus showing a reduced cumulative frequency effect compared to that of the Old Group. We also note the absence of a frequency trajectory effect, as predicted. These findings are in line with other studies showing smaller frequency effects in better educated people (e.g., Tainturier et al., 1992). Additionally, no significant differences were found in the percentage of errors for the different word-types in the More Educated Old Group, including Rare words relative to Dated ones. However, the more educated older adults did make fewer errors on Rare words than the less educated ones, which suggests that these items are accessed more easily by individuals with better education and vocabulary. Overall, these results support the view that cumulative frequency, and experiential factors affecting it, such as education and word knowledge, essentially determined performance in our visual lexical decision task.

Experiment 4

In all three previous experiments, we did not find any frequency trajectory effects in the lexical decision times of older adults, but rather found that performance was influenced by cumulative frequency. One could argue, however, that the assumption we made about the frequency distribution of our stimuli was incorrect: the Dated words were not acquired before Contemporary words, even though their frequency trajectory leads to that assumption. The goal of this next experiment was to verify this assumption. We, therefore, called back the majority of the healthy older participants from both the Old and the More Educated Old Groups, and asked them to rate the age at which they believed they had acquired the Dated and Contemporary words. We did not call back the people with DAT because their dementia is progressive, and besides, the rating task was too difficult for them at this later stage of their disease.

Method

Participants

Fourteen (8 women) of the 15 older adults from the Old Group, and 12 (8 women) of the 15 adults from the More Educated Old Group agreed to rate the different word-types. Statistical analyses with these two subgroups indicated that they did not differ significantly in age [$t(28) = 0.15$, $p = .883$] but the differences in education [$t(28) = 2.99$, $p < .01$], and vocabulary levels [$t(28) = 5.63$, $p < .001$] remained significant, as intended.

Materials and procedure

AoA ratings were obtained for a total of 150 printed words. These included random presentation of the 30 items from each of the four word-types, and a set of 30 Control words, for which Gilhooly and Logie (1980) had obtained AoA ratings. The rating instructions were similar to those used by Gilhooly and Logie, which had, in turn, been adapted from those used by Caroll and White (1973). We used a 7-point scale, but had it cover a wider age range than most rating measures (which usually stop at "over 13 years"), as we had assumed that Contemporary words became more frequent later in life. Each point on the scale represented three-year age bands ranging from 1 (age 2–5 years) to 7 (over the age of 20 years). The scale with corresponding age band remained in view at the top of each rating page.

Results

Average AoA ratings for the experimental stimuli used in the visual lexical decision task and the Control words from Gilhooly and Logie (1980) are presented in Table 5. As can be seen, Dated words received lower ratings than Contemporary words in both groups of older adults.

This impression was confirmed in each group by a t test, which compared the mean AoA ratings for Dated and Contemporary words. The difference in ratings between these two word-types, although surprisingly small, was highly significant in both the Old and the More Educated Old Groups ([$t(58) = 4.10$, $p < .001$] and [$t(58) = 5.07$, $p < .001$], respectively). Similarly, difference in ratings between Contemporary and Popular words was also significant in both groups (Old: [$t(58) = 5.12$, $p < .001$] and More Educated Old: [$t(58) = 5.67$, $p < .001$]), with lower ratings for Popular than Contemporary words. These findings support the assumption that words encountered more frequently early in life are acquired before words encountered frequently later in life. Additionally, no significant difference was found between Dated and Popular words in the Old Group ([$t(58) = 0.66$, $p = .511$]) and in the More Educated Old Group ([$t(58) = 0.45$, $p = .652$]), as both word-types had high frequencies early in life.

Discussion

This last experiment yielded several interesting findings. As predicted, we found that Dated words were rated as being acquired before Contemporary words. Given the time scale that each of the two objective frequency tables encompass (1921/1932/1944 vs. 1967/1982) however, we unexpectedly found a difference of

Table 5
Mean ratings on the different word-types for each group of participants

Group	Word-type				
	Contemporary	Dated	Popular	Rare	Control
Old	4.64	3.71	3.57	5.10	2.78
(*SD*)	(0.88)	(0.89)	(0.75)	(0.82)	(1.39)
More educated old	4.58	3.47	3.56	5.04	2.62
(*SD*)	(0.74)	(0.94)	(0.64)	(0.68)	(1.43)

only three years (approximately 11 vs. 14) between the rated AoA of Dated and Contemporary words. A possible explanation is that AoA ratings obtained from older adults—but typically reported in young adults—are not linear, as we had intended them to be. We can think of many reasons why an older person would find it more difficult to attribute a specific AoA to a word, particularly a Dated one, than a young person. The most obvious reason is that a larger amount of time had elapsed since acquisition in older adults relative to young ones. Given these considerations, until more is known about the validity of AoA ratings in older adults, we have elected not to transpose our rating values directly into actual age of acquisition.

These data, however, can be used to rank the different word-types relative to one another, and provide a general idea about which words were acquired first. Obviously, identifying which words were learned before others is a much easier task for an older adult than to determine the actual AoA of a word, within a three-year limit. The AoA ratings used as a ranking measure may thus provide reliable information. From this standpoint, both groups of older adults clearly believed that the Dated words were acquired before Contemporary ones. It is encouraging as well that the relative AoA ranking of the words by both groups corresponded well to the relative objective frequencies obtained from the early and later word counts. Furthermore, both groups of older adults similarly rated the Dated and Popular words (which were both encountered frequently early in life), and ranked the Rare words as acquired later than the rest of the words. These findings validate Zevin and Seidenberg's (2002) suggestion to use frequency trajectory in the study of age-limited learning effects, on the basis that words encountered more frequently early in life are acquired before those encountered frequently later in life.

Finally, we note that because we have been careful not to translate our ratings into age values, we cannot determine precisely at what age Dated and Contemporary words were acquired by our older participants. Consequently, this raises the possibility that Dated words were acquired past a critical learning period. This issue will be addressed in the General discussion.

General discussion

Zevin and Seidenberg (2002) touched on two important issues for the study of AoA and frequency effects on word learning and recognition. They first suggested that the nature of the task is crucial in determining whether age-limited learning effects are found; tasks involving arbitrary mappings with semantic information appear to be those in which AoA effects are more likely to be found; tasks in which mappings are more consistent, as between orthography and phonology, show reduced or no AoA effects. This assumption has received growing support from both modeling and behavioral studies which compared the size of AoA effects in multi-task performances (Bonin et al., 2004; Ghyselinck et al., 2004; Lambon Ralph & Ehsan, in press). Second, based on the effects of frequency on word acquisition, Zevin and Seidenberg suggested using frequency trajectory to assess age-limited learning effects on performance, as it provides a parsimonious explanation as to why some words are acquired before others. This conceptualization allows one to circumvent the circularity problem that arises when AoA is considered as a lexical property rather than a behavioral one.

Frequency trajectory and cumulative frequency thus provide powerful constructs to investigate age-limited learning effects on later word processing. To examine the effects of these factors across the entire lifespan, we tested older adults and DAT patients on a visual lexical decision task—assumed to involve consistent mappings between representations—with words showing distinct frequency trajectories and cumulative frequencies as a result of natural changes in usage. Our findings are quite clear and consistent with our predictions: no group showed an effect of frequency trajectory. Although we assumed—and confirmed with subjective ratings (Experiment 4)—that Dated words were learned before Contemporary words, our results showed no advantage in lexical decision times of words frequently used in childhood and acquired earlier (Dated words) than words that became frequent later in development (Contemporary words). The absence of a frequency trajectory effect further supports our assumption that consistent mappings are involved in visual lexical decision, as suggested by Zevin and Seidenberg (2002). In turn, such tasks allow for cumulative frequency to play a preponderant role in performance. This is precisely what we observed: Contemporary words were recognized faster than Dated words in both healthy older adults (Experiment 1) and patients with DAT (Experiment 2). Although frequency for Dated and Contemporary words was initially intended to have similar values on the same two tables but at different times in the participant's life, cumulative frequency for Contemporary words was assumed to be greater than for Dated words. This assumption was based on the fact that older participants continued to encounter Contemporary words more frequently than Dated ones for all of their adult life.

The importance of cumulative frequency in visual lexical decision was further demonstrated by showing a reduced frequency effect in an age-matched group of older adults with consistently higher vocabulary scores and education level than that of a less educated group (Experiment 3). These results are compatible with previous studies showing that people with higher education and better vocabulary have smaller frequency effects.

Most importantly, these results do not simply reflect a smaller effect in good performers relative to poor ones; they indicate a differential pattern of performance on the same task by two groups of older adults *matched in terms of age*, and thus assumed to be matched in terms of AoA. In light of the fact that both groups rated the Dated words as acquired before the Contemporary ones (Experiment 4), and that their AoA ratings were comparable, the reduced frequency effect in better educated people further supports the view that frequency is the major determinant of performance in our lexical decision task, not AoA.

Although our findings are in accord with other studies showing little or no AoA effects in tasks where mappings between orthography and phonology are consistent, these results must be compared to other recent studies, which have observed frequency trajectory effects in either visual lexical decision or word naming tasks. In another study of ours, DAT patients were found to perform better on a word naming task with words introduced at an earlier time period than at a later one (Westmacott et al., 2004). It should be noted, however, that the stimuli used in that study often were phrases or compound words (e.g., hep-cat) and were not controlled for many variables which may have interacted with AoA. Interestingly, the age-matched control group did not show the age-limited learning effect observed in patients. In light of our present findings, this latter result suggests that cumulative frequency was equivalent across words from different time periods. A possible explanation for the different findings between patients and age-matched controls, is the use of a different strategy, consciously or not, by these two groups of participants: the particular stimuli used in Westmacott et al.'s study may have encouraged semantic processing in the patient group, which itself could have contributed to the observed AoA effect in this population. Exaggerated semantic effects in tasks assessing STM have been found in DAT patients relative to age-matched controls (Caza & Belleville, Unpublished data). Reliance on such information may occur only in DAT patients, because they must compensate for a broad range of linguistic impairments which follow from global neural deterioration; one possible way to compensate is to use *all* available information to support performance.

Bonin et al. (2004) found a frequency trajectory effect when they re-analysed previous lexical decision data. In that study, they had used non-words that were very word-like, and thus argued that participants used *semantic familiarity* to make lexical decision. Familiarity of both words and non-words has been suggested as a mechanism for making lexical decisions (Atkinson & Juola, 1973; Balota & Chumbley, 1984; Plaut, 1997). When non-words are very word-like, orthographical and phonological representations provide insufficient information about stimulus familiarity, and therefore semantic information is needed to make lexical decisions. As already mentioned, tasks relying on semantic information for optimal performance are those where frequency trajectory effects are most likely to be found. Similarly, Ghyselinck et al. (2004) systematically compared the effects of AoA and frequency in a multi-task investigation using the same stimuli. Results first showed that AoA effects were smaller in the word naming than in the lexical decision tasks (as also reported in Bonin et al.). Additionally, results showed that when the authors varied the non-word stimuli in the lexical decision task, the size of the AoA effect also varied: a small AoA effect was found for illegal non-words, a medium one for legal non-words, and a large effect for pseudo-homophones. These findings suggest that the nature of the stimuli used in lexical decision determines the type of mappings involved in performing the task. Hence, the finding of age-limited learning effects in some lexical decision tasks is not incompatible with the view presented here.

Stadthagen-Gonzalez et al. (2004) also reported evidence for AoA effects in the reaction times of both visual lexical decision and word naming. Based on their RT data, they argued that, in addition to frequency, AoA affects the structure of orthographic and phonological representations, and determines later word processing. Importantly however, Stadthagen-Gonzalez et al. used non-word stimuli that were very word-like. As already mentioned, this may have encouraged the use of semantic information, which has recently been suggested as the possible locus of AoA effects in word processing tasks (e.g., Brysbaert, Van Wijnendaele, & De Deyne, 2000).

We suspect, however, that the type of non-words used does not entirely account for the finding of an AoA effect in Stadthagen-Gonzalez et al.'s (2004) study. One reason is that we also used non-words that were very word-like, and did not observe any effect from frequency trajectory. Interestingly, inspection of our stimuli shows that the majority of our *words* are abstract, while those used by Stadthagen-Gonzalez et al. had high values of concreteness (word stimuli in Experiment 2 had an average rating of about 5.5 out of a maximum of 7). There is evidence showing that word meaning, and variables known to index it such as concreteness/imageability, affect performance in lexical decision tasks (e.g., Chumbley & Balota, 1984; Kroll & Merves, 1986). The use of concrete words rather than abstract ones may have contributed to making semantics more readily available in Stadthagen-Gonzalez et al.' study than in ours. Although further experiments are necessary to validate this assumption, the evidence suggests that the nature of both word and non-word stimuli in lexical decision may either encourage or discourage the use of semantic information, which in turn may determine whether age-limited learning effects are found.

As a final point, we must consider yet another alternative interpretation for our data. Because the learning curve follows a concave function (differences are bigger in the earlier part than in the later one), we cannot rule out the possibility that Dated words were acquired past a critical period, which typically corresponds to puberty. Although the subjective AoA ratings put the acquisition of Dated words before or around puberty, not past it, we do not know if these measures are reliable, as already explained. However, Dated words were selected from a corpus reflecting general readings by children and young people (Thorndike, 1921, 1932; Thorndike & Lorge, 1944). Furthermore, as the participants were born, on average in 1925, Dated words were frequently in use during a period that encompasses the older adults' childhood. In any case, a reduced age-limited learning effect, leading to similar performances with Dated and Contemporary words, would have been expected. Rather, results showed a reversed AoA effect in both healthy older adults and DAT patients. Clearly, there is a need for future behavioral and modeling studies addressing the different questions raised here, including the validity of AoA rating in older adults.

In summary, our findings, based on objective measures of frequency trajectory, show little or no AoA effects in lexical decision of healthy older adults and people with DAT. Overall, the results support the hypothesis that AoA effects are absent in tasks where mappings between orthography and phonology are consistent, and do not rely on semantic information for optimal performance. Instead, performance seems to be determined by cumulative frequency, and factors known to affect it. Sometimes, however, certain stimuli and population types may encourage the use of semantically related information and lead to age-limited learning effects, even if the task may be performed using essentially consistent mappings.

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Appendix

Stimuli and performance data for DAT patients and old participants

Word	DAT		Old	
	Mean	*SD*	Mean	*SD*
Contemporary				
Abstract	1848.64	712.81	801.20	152.22
Allotment	1812.75	579.31	1119.53	445.62
Artery	1764.64	979.97	871.00	345.37
Binomial	1706.25[b]	745.27	1594.27[a]	1219.09
Component	1615.64	493.08	845.27	192.81
Emission	1716.22	1015.17	818.79	128.31
Equation	2040.80	1284.70	848.73	221.97
Fiscal	1754.82	733.15	834.57	164.36
Integration	2026.00	779.55	1129.80	368.47
Jurisdiction	2098.55	958.84	1640.40[a]	833.23
Legislative	1802.50	889.32	1274.07	345.57
Nuclear	1445.60	582.68	934.47	262.17
Onset	1951.10	1567.50	812.79	178.58
Organic	1463.82	441.44	801.79	164.64
Outlook	1572.00	603.11	716.64	109.72
Pathology	1797.18	762.76	918.36	239.32
Practical	1878.82	895.80	860.14	283.00
Premier	2114.50	1025.33	808.40	207.46
Pursuant	2010.89	595.38	997.38	257.26
Radiation	1402.00	490.61	959.00	296.59
Saline	2169.43	1493.97	930.92	225.50
Sewage	1484.10	525.79	767.07	251.82
Symbolic	1967.18	990.86	799.86	118.70
Tangent	2172.67	1240.40	899.21	179.01
Technology	2055.36	1149.07	1114.71	323.69
Theological	2243.18	667.37	1075.85	299.00
Thermal	2074.60	1266.61	803.21	166.61
Variable	2042.00	1054.14	832.00	161.80
Vehicle	1635.55	798.32	838.29	269.84
Velocity	3195.82[a]	2594.13	862.60	236.83
Mean	1855.73		902.70	
Dated				
Accessory	2229.73	1211.57	843.21	209.65
Alcove	2489.90	1418.28	940.08	531.07
Armistice	2608.13	2016.68	1085.64	361.92
Bayonet	1937.50	876.96	1032.80	578.86
Bewilderment	1931.55	841.64	1376.50	709.60
Boiler	1418.44	496.36	808.67	152.96
Calamity	2103.55	856.48	1033.87	374.20
Caraway	6075.60[b]	4969.83	1404.45	612.02
Clergyman	1865.90	684.65	1055.87	457.37
Constable	1585.80	689.64	997.29	287.85
Creditor	1715.91	812.67	860.67	167.62
Disregard	2259.09	1167.21	901.86	196.07
Enamel	1446.36	534.73	809.50	179.95
Flutter	2556.91	2292.18	856.86	120.45
Immaculate	1731.38	771.79	not presented	
Inconspicuous	2901.70	1559.10	1282.08	377.79
Interlude	1610.67	448.94	909.14	239.53
Linoleum	2611.33	1245.30	1208.14	478.56
Matrimony	1725.82	544.30	1022.71	364.85
Oblong	1933.00	1110.09	818.36	182.39

Appendix (*continued*)

Word	DAT		Old	
	Mean	*SD*	Mean	*SD*
Oilcloth	1790.09	759.85	948.00	258.37
Procession	1610.10	794.94	1008.47	319.43
Sallow	3343.00[b]	3977.06	1395.40	871.70
Shilling	1765.78	949.37	1150.57	411.04
Shrubbery	1996.10	1347.84	919.29	255.50
Swindle	1506.78	696.61	914.93	355.11
Tenement	2029.90	649.39	1242.69	404.05
Tinkle	1558.88	655.29	892.79	310.01
Veritable	2082.80	864.61	1256.50	473.75
Vicinity	1867.09	948.92	849.73	228.65
Mean	1959.65		1028.49	
Popular				
Adequate	1704.45	731.04	805.93	221.93
Alternative	1863.70	743.60	1126.93	351.37
Assistance	1487.82	591.73	926.13	244.15
Cattle	1791.09	808.40	844.47	276.06
Chemical	1605.18	722.29	798.36	165.04
Collective	1528.40	801.54	885.14	216.82
Combat	1497.70	598.43	772.15	164.13
Consistent	1741.09	684.36	1088.20	327.79
Critical	1512.80	507.83	825.07	187.39
Definition	1593.55	677.00	955.62	304.90
Diameter	1426.10	523.72	762.20	140.73
Emphasis	1377.22	439.39	984.64	385.50
External	1577.91	345.51	918.27	228.86
Festival	1382.67	625.83	1019.93	501.74
Initial	1564.82	727.47	818.64	135.14
Intensity	1570.80	795.10	920.40	190.17
Marine	1588.60	572.70	775.08	138.54
Mechanism	1514.60	471.29	1222.33[a]	716.40
Neutral	1709.18	740.18	796.27	211.60
Outcome	1333.64	546.19	794.47	233.24
Oxygen	1418.90	460.76	699.53	103.84
Participation	1558.50	555.92	1003.07	228.12
Patrol	1357.50	490.27	703.38	162.98
Philosophy	1642.56	722.93	972.00	304.23
Poetry	1219.00	417.41	770.93	172.48
Precise	1551.91	656.70	782.79	126.82
Random	1478.91	620.87	1000.47	432.06
Secondary	1765.36	875.30	999.40	406.11
Substantial	1638.40	880.28	2443.5[b]	1954.88
Target	1614.00	741.89	707.07	156.17
Mean	1553.88		873.45	
Rare				
Adamant	1556.44	491.78	1130.47	387.87
Adjunct	2510.38	2585.39	1025.86	434.78
Amulet	2485.57	2022.92	1029.67	301.81
Baronial	1205.75[b]	535.36	1112.88	387.81
Bullish	1696.86	499.90	939.62	316.40
Ebullient	1919.67[b]	664.04	1580.22[a]	988.23
Effusive	1999.11	774.43	958.42	407.28
Embodiment	2131.27	707.88	1149.14	254.33
Fishery	1597.91	573.83	827.14	160.12
Fusion	2175.78	1353.06	855.33	189.86

Appendix (*continued*)

Word	DAT		Old	
	Mean	*SD*	Mean	*SD*
Imprecation	3008.00[b]	1185.11	1607.75[b]	462.64
Jocular	1746.00	575.33	887.21	317.52
Litigation	1592.00	506.94	1172.58	345.37
Monsoon	2323.13	1758.95	1202.14	474.51
Murky	1976.57	1422.23	958.00	218.20
Nebular	3921.40[b]	3272.39	1018.92	272.02
Obverse	3122.17	1987.28	1253.50	409.70
Partaker	2989.00	1637.88	1274.71	518.04
Pestilent	3744.13	3457.17	1324.00	369.77
Primeval	2495.88	2290.65	1308.85	849.84
Proficient	2156.82	1247.60	1178.00	610.37
Provisional	2021.00	1114.31	1131.15	311.18
Repudiation	2159.83	987.32	1492.77	441.65
Saffron	2663.29	1971.50	1166.83	297.93
Seminary	1687.91	660.85	793.57	230.97
Sporadic	2128.60	1226.27	1176.15	420.29
Stoppage	1566.27	495.08	881.14	188.88
Subsidiary	2741.00	2265.07	1060.29	425.17
Torpid	1743.50[b]	697.54	961.30	242.99
Venerable	2578.33	1299.07	977.79	277.32
Mean	2233.81		1080.27	

[a] The RTs for this word are not included in the statistical analyses based on the exclusion criteria (see details in Experiment 1).

[b] The RTs for this word are not included in the statistical analyses as less then 50% of the participants correctly recognized it.

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