Journal of Gerontology: PSYCHOLOGICAL SCIENCES
2007, Vol. 62B, No. 6, P340–P342

Aging and Lexical Inhibition: The Effect of Orthographic Neighborhood Frequency in Young and Older Adults

Christelle Robert and Stéphanie Mathey

Department of Psychology, Université Bordeaux 2, France.

The aim of this study was to examine whether the lexical inhibition underlying orthographic neighborhood effects in visual word recognition is changed with aging. To do so, orthographic neighborhood frequency was manipulated for French words that had either no higher frequency neighbor (e.g., *taupe*), or at least one higher frequency neighbor (e.g., the word *loupe* has two higher frequency neighbors, *coupe* and *soupe*). Young adults (mean age = 20.9 years) and older adults (mean age = 67.8 years) performed a standard lexical decision task. An interaction was found between age group and orthographic neighborhood frequency on word latencies. More precisely, an inhibitory effect of neighborhood frequency was observed for the young adults but not for the older ones. These data are consistent with the assumption of an age-related decline in lexical inhibition and activation. The findings are discussed in the framework of visual word recognition and aging.

PRIOR research in visual word recognition has demonstrated that words that are orthographically similar to a more frequent word (e.g., *grain–train*) take longer to identify than those with no such higher frequency orthographic neighbor (e.g., *fugue*). Grainger, O'Regan, Jacobs, and Segui (1989) referred to this result as the neighborhood frequency effect (NFE; see Andrews, 1997; Mathey, 2001 for reviews). In the interactive-activation model (McClelland & Rumelhart, 1981), the NFE is attributed to lexical inhibition at the word level (Grainger et al.; Mathey & Zagar, 2006). Upon the visual presentation of a word, orthographically similar words become partially activated and compete with each other. Thus, the stimulus word inhibits and receives inhibition from its orthographic neighbors. The inhibitory capacity of a given competitor is a function of its frequency (corresponding to its resting activation level). Stimulus words with higher frequency neighbors therefore receive more inhibition than those with no such neighbors. This interpretation was further supported by simulations run with the interactive-activation model on natural and artificial lexica (e.g., Mathey & Zagar, 2000; Zagar & Mathey, 2000). In this theoretical framework, lexical inhibition operating at the word level is a critical mechanism in visual word recognition. On the basis of these concerns, in the present study we address the issue of an age-related change in lexical inhibition efficiency by examining the magnitude of the NFE in a lexical decision task performed by young and older adults.

A dominant view in the aging literature is that age-related cognitive changes are caused by a failure of inhibitory mechanisms on the part of older adults (Hasher & Zacks, 1988). Much empirical evidence for an inhibitory deficit has been provided in the selective attention field, whereas it is sparser in other cognitive domains, such as single-word processing (Burke, 1997). Nevertheless, examining whether lexical inhibition changes with aging has strong implications, because lexical inhibition has been shown to be a critical mechanism underlying visual word recognition (McClelland & Rumelhart, 1981; see also Mathey & Zagar, 2006). It also raises the question of whether Hasher and Zacks' inhibitory deficit theory, which was initially developed to account for a decline in attentional mechanisms, can be extended to lexical processes. Until now, little information has been available on possible age differences in lexical inhibition efficiency. With regard to the visual word recognition literature, to our knowledge only one lexical decision experiment has been conducted in English to investigate age effects in the NFE (Stadtlander, 1995). Neither a main NFE nor any interaction with age was observed. However, it is difficult to draw any firm conclusion from this study concerning a possible change of lexical inhibition with aging. In fact, an inhibitory NFE is difficult to observe in English (for reviews, see Andrews, 1997; Mathey, 2001). Less consistent spelling–sound relationships in English may be a possible explanation (Andrews), but this is not sufficient to account for the whole pattern of findings (Mathey). Several confounds that are known to influence lexical latencies, such as subjective frequency or neighbor spread across letter positions (see Mathey & Zagar, 2000; Zagar & Mathey, 2000), might also explain the lack of NFE in previous studies. Thus, the issue of an age-related decline in lexical inhibition remains to be investigated.

Our aim in the present study was to examine whether and to what extent the NFE in the lexical decision task changes with aging. In the interactive-activation framework, the NFE can be considered as an estimate of lexical inhibition efficiency in visual word recognition. If we assume that lexical inhibition efficiency decreases with aging, then the inhibitory strength of the higher frequency neighbors should be weaker for the older adults than for the younger ones. In other words, the differential processing of words with and without neighbors should be less salient with aging. Following this rationale, we expect that older adults will exhibit a smaller NFE than young adults.

METHODS

Participants

A total of 54 adults participated in the experiment. All were native French speakers and reported having normal or

Table 1. Mean Empirical Data for Orthographic Neighborhood Frequency and Age Group, and Mean Simulated Data for Four Variants of the Interactive-Activation Model

	Higher Frequency Neighbors		
Data	None	Several	NFE
Empirical			
Young adults			
Latencies (ms)	650	683	33
Error rates	2.3	4.7	2.4
Older adults			
Latencies (ms)	710	713	3
Error rates	2.1	3.7	1.6
Simulated			
Original model	18	21	3
Inhibition-decreased model	18	19	1
Excitation-decreased model	24	27	3
Inhibition- and excitation-decreased model	24	24	0

Note: NFE = neighborhood frequency effect. For simulated data, time is expressed in cycles.

corrected-to-normal vision. Twenty-seven young adults (age, $M = 20.9$ years, $SD = 2.1$, range = 18–25) were students from the University of Bordeaux and averaged 13.2 years of education ($SD = 1.5$, range = 12–17). Twenty-seven older adults (age, $M = 67.8$ years, $SD = 4.9$, range = 61–79) were recruited from the adult education courses at the University of Bordeaux and averaged 13.2 years of education ($SD = 2.8$, range = 9–17).

Young and older participants did not differ significantly on education years ($t < 1$). We had the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) administered to both groups, and it indicated no reliable age difference ($M = 29.2$, $p > .10$). All participants completed the French version of the Mill Hill vocabulary test (Deltour, 1998). Younger adults scored lower on this test ($M = 35.6$ out of 44, $SD = 1.7$, range = 32–39) than the older adults did ($M = 38.4$ out of 44, $SD = 3.7$, range = 28–43), with $t(52) = 3.6$, $p < .001$.

Stimuli

We selected 64 five-letter words in the French lexical database, BRULEX (Content, Mousty, & Radeau, 1990). We manipulated neighborhood frequency. Half of the words had no higher frequency orthographic neighbor (e.g., *sucre*). The other half had at least one higher frequency orthographic neighbor concentrated on a single letter position ($M = 1.8$; e.g., *vigne–ligne, signe, digne*) so that neighborhood distribution was controlled (Mathey & Zagar, 2000). Objective frequency (in log units) was matched across the word conditions ($M = 2.81$, $t < 1$), as was subjective frequency estimated on a 7-point scale by 15 young adults ($M = 3.15$, $t < 1$) and 15 older adults ($M = 3.12$, $t < 1$) who did not participate in the experiment but were recruited in the same population as the other participants. For task purposes, we generated 43 five-letter pseudowords by changing one or two letters in real words. All were pronounceable and orthographically legal.

Procedure

We used a standard lexical decision task. All stimuli (in Courier New font, with a type size of 42 points) were centered on a black background on a 17-in. (43.2-cm) monitor. For each trial, a 500-ms fixation cross was followed by a lowercase stimulus that remained on the screen until the participant responded or until 2,500 ms had elapsed. We instructed participants to decide as quickly and as accurately as possible whether the stimulus was a word or not by pressing one of two buttons on a response box. "Yes" responses (for words) were given with the dominant hand and "no" responses (for pseudowords) were given with the other hand. We provided tone feedback when participants failed to respond. We randomized the presentation of the stimuli for each participant. We conducted 16 practice trials before the experiment started. We measured reaction times from word onset until the participant responded.

Results

We excluded reaction times below 300 ms or above 1,500 ms from the analyses (0.4% of the data). We eliminated two words because of their high error rates (more than 40%). We also eliminated two words that were matched in frequency in order to keep the matching of the materials across the conditions. We submitted correct response latencies and error rates to separate analyses of variance on the participant means ($F1$) and item means ($F2$), with age group and orthographic neighborhood frequency as main factors. The mean correct response latencies and error rates on words, averaged over participants, are presented in Table 1.

An analysis of the reaction times showed that the Age × Orthographic Neighborhood Frequency interaction was significant, $F1(1, 52) = 11.8$, $\eta^2 = .19$, $p < .01$, and $F2\,(1, 58) = 8.1$, $\eta^2 = .12$, $p < .01$. An inhibitory orthographic neighborhood frequency effect was found for the young adults (33 ms) but not for the older ones (3 ms). The main age-group effect was marginally significant in the participant analysis, $F1(1, 52) = 3.7$, $\eta^2 = .07$, $p = .06$, and significant in the item analysis $F2(1, 58) = 61.2$, $\eta^2 = .51$, $p < .001$. Young adults were 45 ms faster on average than older adults were. The orthographic neighborhood frequency effect was significant only in the participant analysis, $F1(1, 52) = 18.3$, $p < .001$, $\eta^2 = .26$, but $F2(1, 58) = 2.0$, $\eta^2 = .03$, $p = .16$. An analysis of the errors showed a significant effect of orthographic neighborhood frequency, $F1(1, 52) = 16.3$, $\eta^2 = .24$, $p < .001$, and $F2(1, 58) = 4.7$, $\eta^2 = .08$, $p < .05$. Words with higher frequency neighbors generated an average of 2.0% more errors than did words with no higher frequency neighbor. No other effects were significant.

To check whether the results might be ascribed to vocabulary scores across age groups, we conducted an analysis of covariance on the NFE (in milliseconds) computed for each participant. We observed a significant age-group effect on the NFE even when we controlled for vocabulary scores: $F1(1, 51) = 15.6$, $p < .001$, $\eta^2 = .23$. This suggests that the variation of NFE during aging is not attributed to an age-linked difference in verbal ability.

Discussion

The inhibitory NFE that we observed for the young adults replicates previous findings (e.g., Grainger et al., 1989; Mathey & Zagar, 2006) that show that words with higher frequency neighbors are harder to recognize than are words with no such neighbors. This confirms that lexical inhibition is a critical mechanism in visual word recognition (McClelland & Rumelhart, 1981). The most important finding is the Age × Neighborhood Frequency interaction. Contrary to the young adults, the older adults did not exhibit any NFE, as they processed words as rapidly whether they had or did not have orthographic neighbors. It should be noted that the interaction failed to reach significance in the error data, probably owing to an overall low error rate for both age groups (less than 5%). In the interactive-activation framework (McClelland & Rumelhart), this interaction can be interpreted in terms of a decrease in inhibitory efficiency that leads to the situation in which orthographic competitors exert too little inhibition toward the stimulus to interfere in its recognition. These findings also have strong implications for Hasher and Zacks's (1988) inhibitory deficit theory, because it extends the age-linked inhibitory decline to single-word processing.

An explanation that has been suggested to account for age differences in visual word recognition performance for words with no higher frequency neighbors is that aging could weaken excitatory processes (Mathey & Postal, 2003). In the case of words with neighbors, a deficit in excitatory processes might result in a situation in which neighbors are not sufficiently activated to influence word recognition. Thus, a decrease in inhibition efficiency or activation efficiency, or both, might explain the present data. To address this issue, we ran simulations with an artificial lexicon that was constructed to represent the word conditions used in the experiment (for the same procedure, see Mathey & Zagar, 2000; Zagar & Mathey, 2000). We reduced this lexicon to the representations of two low-frequency stimulus words, namely *aaaa* and *bbbb*, with a resting activation level of –0.9. The stimulus *aaaa* had no higher frequency neighbor, whereas the stimulus *bbbb* had one higher frequency neighbor (i.e., *ebbb*, with a resting activation level of –0.1). As shown by Zagar and Mathey, it is possible to disentangle the respective role of activation and inhibition processes by changing the weight of parameters in the interactive-activation model. We then ran simulations with the original interactive-activation model and with three variants of this model in which either the intraword inhibition parameter, the feature-to-letter excitatory parameter, or both parameters were decreased. We recorded the number of processing cycles for the two stimuli to reach the decision criterion (.68). The results are presented in Table 1. As expected, the interactive-activation model with its original parameters captured the inhibitory NFE (three cycles), supporting the data found for the young adults and replicating previous empirical and simulated findings (e.g., Grainger et al., 1989; Zagar & Mathey).

In the inhibition-decreased model, we simulated the hypothetical age-related decrease in lexical inhibition by reducing the word-to-word inhibitory parameter by one third (from .21 to .07). Although the change in the NFE was in the same direction as expected, it incorrectly predicted a slight NFE (one cycle) and a faster lexical access that was not observed in the elderly individuals. Note that the slowed performance found in elderly persons might be explained by the general cognitive slowing theory (Salthouse, 1996). However, by positing that all processing stages are slowed by a rate that is proportional to overall latency, this model incorrectly predicts a larger NFE with aging. Another possibility would be that the slowed performance is due to a slowing in response execution in the elderly individuals. However, this does not account for the Age × Neighborhood Frequency interaction. In the excitation-decreased model, we simulated a decrease in excitatory processes by reducing the feature-to-letter excitatory parameter from .005 to .002. The slowed performance was captured, but a preserved NFE (three cycles) was incorrectly predicted. This reaffirms the importance of inhibition to explain the NFE. Finally, a model in which both excitatory and inhibitory processes were decreased provided the best fit to the data found in the elderly persons with a lack of NFE and slowed latencies. Thus, the present findings provide evidence for a deficit of inhibitory processes with aging and are consistent with the proposition of an age-related decline in activation processes (Mathey & Postal, 2003). Further, the assumption of a decrease in lexical inhibition efficiency is necessary to explain a decrease in the NFE with aging. Future research should help to disentangle the respective modification of lexical activation and inhibition processes during aging.

Correspondence

Address correspondence to Christelle Robert, who is now at the University of Geneva, Faculty of Psychology and Educational Sciences, Bd du Pont-d'Arve 40, CH-1211 Genève 4, Switzerland. E-mail: Christelle.Robert@pse.unige.ch

References

Andrews, S. (1997). The effect of orthographic similarity on lexical retrieval: Resolving neighborhood conflicts. *Psychonomic Bulletin & Review, 4,* 439–461.

Burke, D. M. (1997). Language, aging, and inhibitory deficits: Evaluation of a theory. *Journal of Gerontology: Psychological Sciences, 52B,* P254–P264.

Content, A., Mousty, P., & Radeau, M. (1990). BRULEX: Une base de données lexicales informatisée pour le français écrit et parlé. *L'Année Psychologique, 90,* 551–556.

Deltour, J. J. (1998). *Echelle de vocabulaire Mill Hill de J. C. Raven.* Paris: Editions et Applications Psychologiques.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189–198.

Grainger, J., O'Regan, J. K., Jacobs, A. M., & Segui, J. (1989). On the role of competing word units in visual word recognition: The neighborhood frequency effect. *Perception and Psychophysics, 45,* 189–195.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. M. Bower (Eds.), *The psychology of learning and votivation. Advances in Research and Theory, 22* (pp. 193–225). New York: Academic Press.

Mathey, S. (2001). L'influence du voisinage orthographique lors de la reconnaissance des mots écrits. *Revue Canadienne de Psychologie Expérimentale, 55,* 1–23.

Mathey, S., & Postal, V. (2003). Vieillissement et accès au lexique: Etude dans une tâche de décision lexicale. *Bulletin de Psychologie, 56,* 49–55.

Mathey, S., & Zagar, D. (2000). The neighborhood distribution effect in visual word recognition: Words with single and twin neighbors. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 184–205.

Mathey, S., & Zagar, D. (2006). The orthographic neighbourhood frequency effect in French : A letter-case manipulation study. *Canadian Journal of Experimental Psychology, 60,* 137–143.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88,* 375–405.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103,* 403–428.

Stadtlander, L. M. (1995). Age differences in orthographic and frequency neighborhoods. In P. A. Allen & T. R. Bashore (Eds.), *Age differences in word and language processing* (pp. 72–86). Amsterdam: Elsevier.

Zagar, D., & Mathey, S. (2000). When words with higher-frequency neighbours become words with no higher-frequency neighbours. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 23–46). Oxford, England: Elsevier.

Received February 28, 2007
Accepted July 11, 2007
Decision Editor: Thomas M. Hess, PhD