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The Time Course of Lexical Competition in Young and Older Adults

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Abstract

Although hearing loss accounts for much of the difficulty older adults have comprehending spoken language, cognitive factors also play a role. There is evidence that, relative to younger listeners, older listeners have more difficulty recognizing a word when it has many lexical competitors, but little is known about the time course of lexical competition in older adults. We monitored the eye movements of sixteen young adults (18-30 years) and sixteen older adults (60-80 years) as they followed spoken instructions to click on objects displayed on a computer screen. We manipulated the lexical frequencies of the target word and the phonologically similar competitor. Older listeners were more likely than younger listeners to fixate competitors during comprehension only when the competitor was high frequency. Simulations using a model of spoken word recognition suggest that these age differences may arise from a combination of differences in the effect of frequency and competitor inhibition.

Keywords: cognitive aging; spoken word recognition; visual world paradigm.

Introduction

Theories in cognitive aging have long focused on the seeming difficulty that older adults have in selecting between competing representations during processing (Hasher & Zacks, 1988). Indeed, older adults are disadvantaged in situations when multiple mental representations compete for selection. While this can be seen most clearly in areas such as attentional control (e.g., Spieler, Balota, & Faust 1996), selection during language processing is also adversely influenced. For example, during language production, older adults have particular difficulty in lexical selection (LaGrone & Spieler, 2006). Here, we focus on another aspect of selection, namely the need to select the correct word from a set of competing lexical candidates during spoken language comprehension. Because spoken language input arrives incrementally, competition occurs between similar word representations during moments of temporary ambiguity. In most current models of spoken word recognition (SWR), the acoustic input activates multiple lexical candidates that compete for eventual recognition (though see Norris & McQueen, 2008 for a Bayesian perspective on activation and competition).

Spoken Word Recognition and Aging

Although language abilities are frequently cited as being relatively preserved in old age, older adults do have difficulty with spoken language comprehension under a variety of circumstances. Most of this difficulty (up to 80% of the variance in some studies) can be attributed to presbycusis, an age-related reduction in auditory sensitivity starting at high frequencies and progressing into the lower frequencies with age (Humes et al., 1994). However, cognitive changes also affect older adult performance above and beyond what is predicted by auditory thresholds. In the visual word processing literature, the lexical frequency of the target word itself has been shown to have a larger influence on older compared to younger adults (Spieler & Balota, 2000). In spoken word recognition, factors like neighborhood density and neighborhood frequency (the average lexical frequency of all of the words in the neighborhood) affect word identification in both young and older adults (Sommers, 1996; Sommers & Danielson, 1999). Like young adults, older adults have more difficulty identifying ‘difficult’ words (words from high density, high frequency neighborhoods) than ‘easy’ words (words from low density, low frequency neighborhoods). However, the disadvantage for difficult words is increased for older adults even after equating for acuity.

While neighborhood structure and density affect the time course of lexical competition in young adults (Magnuson et al., 2007), little is known about age differences in the time course of competition. Some evidence is available from gating paradigms. Here, listeners hear increasing fragments of a word and are asked to identify the word. Older listeners needed to hear slightly more of a word than younger listeners (57% versus 52% respectively) before correct identification (Wingfield, Aberdeen, & Stein, 1991). Because participants make responses long after the offset of the word fragment, this evidence is only a very indirect measure of the time course of recognition.

If older adults need to hear more of a word before identification occurs, then lexical activation may simply build more slowly in older compared to younger listeners. This slowed time course of activation need not influence the overall pattern of competition between target words and phonologically related “cohort” competitors. However, older adults’ increased difficulty with identification of words in hard neighborhoods and the observation of larger effects of lexical frequency in visual word identification studies suggest that age differences may result from increased competition from high frequency competitors instead of an overall delay in lexical activation. More direct information about the time course of lexical activation and competition is needed to distinguish these alternatives. If the age difference is due to differences in the resolution of competition, then we would expect differences in the patterns of activation primarily when competitors compete strongly with the target word, for example, when the target is a low frequency word and the competitor is high in frequency. When competition is low, the activation patterns should be similar.

Using Eye Movements to Examine the Effects of Age on the Time Course of Lexical Competition

In general, people look at things that are related to their current thoughts and upcoming actions. The visual world paradigm takes advantage of this by measuring patterns of eye fixations to objects or pictures while listeners hear spoken words. In goal-directed tasks, participants' eye movements are closely time-locked to the unfolding spoken instruction. Fixation proportions can be used as an index of lexical activation and competition across time (Allopenna, Magnuson, & Tanenhaus, 1998; Magnuson et al., 2007). The relative effortlessness of eye movements gives us an important advantage over prior examinations of age differences in spoken word recognition. Many experimental tasks impose secondary demands on participants (for example, planning and executing a button push or a spoken response) that can contribute to age differences unrelated to the process of interest. Eye movements are a natural and low-effort form of responding that impose minimal secondary demands on listeners. Here, we observe the time course of eye fixations of younger and older listeners while they hear words that vary in terms of likely competition from other words in the lexicon.

Using TRACE to Explore Mechanisms of Increased Lexical Competition in Older Adults

An additional benefit of using the visual world paradigm to explore age differences in the time course of spoken word recognition is that fixation proportions can be linked to the activation levels of lexical representations in the TRACE model of speech processing (Allopenna et al., 1998; McClelland & Elman, 1986). We use an implemented model (jTRACE, a recent reimplementation by Strauss, Harris, & Magnuson, 2007) to better understand how cognitive factors lead to differences in the time course of young and older adult spoken word recognition.

The Experiment

Methods

Participants. Sixteen young adults (ages 18-23, mean 19.6) with normal or corrected-to-normal vision and self-reported normal hearing were recruited from the Georgia Tech community. All were native English speakers. In addition, 16 community-dwelling older adults (ages 69-80, mean 73.6) with normal or corrected-to-normal vision were recruited from the surrounding community. All were native English speakers with self-reported good hearing and no history of neurological disease. All of the younger adults and 12 of the 16 older adults reported using a computer on a daily basis; the remaining older adults reported occasional computer use and were capable of using a mouse to point to and click on items on a computer screen. Young adults received course credit for participation; older adults were paid $10/hr.

Materials. Fifteen pairs of cohort competitors were selected as critical stimuli. Twelve pairs consisted of two monosyllabic words that differed only at the final consonant (or consonant cluster), and three pairs consisted of two bisyllabic words with overlapping first syllables. One member of each pair had a relatively low frequency (11.1/million ± 12) and one had a relatively high frequency (110.9/million ± 72) according to the CELEX English database (Baayen, Piepenbrock, & van Rijn, 1993). Each pair of objects appeared in two critical trials (along with two phonologically unrelated objects), once with the HF word as the target and once with the LF word as the target. All words referred to picturable items. Matching pictures were selected from a commercially available full-color digital picture set, with the majority coming from a subset that has been normed for name agreement across young and older age groups (LaGrone & Spieler, 2006). An additional 145 pictures were selected from this set for use as distracters on critical trials and on filler trials.

The stimuli were recorded by a male native speaker of American English. Each word was embedded in the sentence "Click on the TARGET." To minimize variability in target onset times while keeping coarticulation cues as natural as possible, the phrase "the TARGET" was excised as a unit out of each utterance and spliced onto a single "Click on" phrase. The "Click on" instruction was 534 ms long, and the duration of the "the TARGET" phrase was, on average, 702 ms for the critical trials and 701 ms for the filler trials.

Procedure. The experiment consisted of 80 trials: twenty practice trials, thirty critical trials and thirty filler trials. Each cohort pair appeared in two critical trials, once with the high frequency item as the target and once with the low frequency item as the target. On the filler trials, the frequencies of the targets were closely matched to the frequencies of the target items in the critical trials (HF filler targets ~ 116.5/million, LF filler targets ~ 11.2/million).

During the experiment, participants were seated approximately 60 cm in front of a computer monitor. Participants' eye movements were monitored using an EyeLink head-mounted eyetracker sampling at 250 Hz. Auditory stimuli were presented over Sennheiser HD 280 Pro headphones. Before beginning the experiment, the eyetracker was calibrated and validated using a standard nine-point calibration routine.

At the beginning of each trial, participants fixated and clicked on a central fixation cross to correct any drift from the initial nine-point calibration. Four pictures, each spanning approximately 5 degrees of visual angle, appeared on the screen. On cohort trials, two cohort competitors and two phonologically unrelated distracter items were present. The spoken instruction began five hundred milliseconds after the pictures appeared. Participants then clicked on the named picture. Both eye movement and mouse response data were collected.

The first twenty trials were practice trials used to familiarize participants with the task. The remaining sixty trials were presented in a different pseudo-random order to each participant so that critical and filler trials were intermixed and so that only one member of each cohort pair was the target in the first half of the experiment. In addition, target and cohort position on the screen were counterbalanced to ensure that common scanning patterns did not bias the overall likelihood of target or cohort fixations during preview.

Results

All participants were able to perform the task with a high degree of accuracy (mean accuracy = 98.3% correct, all participants > 90% correct). Data from incorrect trials was excluded from further analysis. Older adults took approximately 425 ms longer than young adults to click on the correct picture once it was named, regardless of whether the target was high or low frequency. A 2 (Age) by 2 (Target/Distracter Frequency) mixed factor ANOVA examining the time between the onset of the target word and the mouse click on the correct object showed significant effects of lexical frequency [F (1,30) = 13.9, p < 0.01] and age [F (1,30) = 53.7, p < 0.001], but no interaction [F < 1].

Fixation proportion curves were calculated from the eye movement data for the target, cohort competitor, and an averaged unrelated distracter for each individual in each condition. As shown in Figure 1, both young and older adults show the typical cohort effect, with early looks to both the target and the competitor and a gradual decline in competitor fixations as the target is disambiguated. Although the time from the onset of the critical word to the mouse click differed in young and older participants for high frequency target words, the fixation proportion curves look remarkably similar, suggesting that when competition demands are low (i.e. the target has a large frequency advantage over a low frequency cohort competitor), young and older adults show comparable effects of lexical competition (Figure 1, top panel). Traditional analysis of variance models are less than ideal for assessing time course data from the visual world paradigm (Mirman, Dixon, & Magnuson, 2008). Following examples from Singer & Willett (2003) and Mirman et al (2008), we used growth curve analysis to examine the time course of target activation. Growth curve analysis is specifically designed to assess individual change over time, and though it has primarily been used for exploring the time course of development or other types of longitudinal data, it can also be used for data collected at a rapid rate over a shorter time scale. When considering target activation data arising from eye movements in the visual world paradigm, a simple linear fit is not adequate. To capture the general sigmoid form of these curves, we used a third order orthogonal polynomial to fit the data. The two most important parameters of the model for capturing differences in target activation curves are the intercept, which shifts the vertical height of the curve and can measure differences in overall activation levels (as estimated by participants' eye movements), and the linear term, which reflects the overall angle of the curve and can account for differences in the rate of rise of activation. The model's baseline fit with participant as a random factor is evaluated using a deviance statistic based on the log likelihood. We can then ask if adding Age as a fixed effect results in a significant improvement in model fit. Turning first to the low competition condition (high frequency target, low frequency competitor), there was no benefit in adding the age term to the intercept or to the linear model (Table 1), indicating that young and older adults' fixation proportion curves were not significantly different. In contrast, under high competition conditions (low frequency target, high frequency competitor) we find clear age differences in the

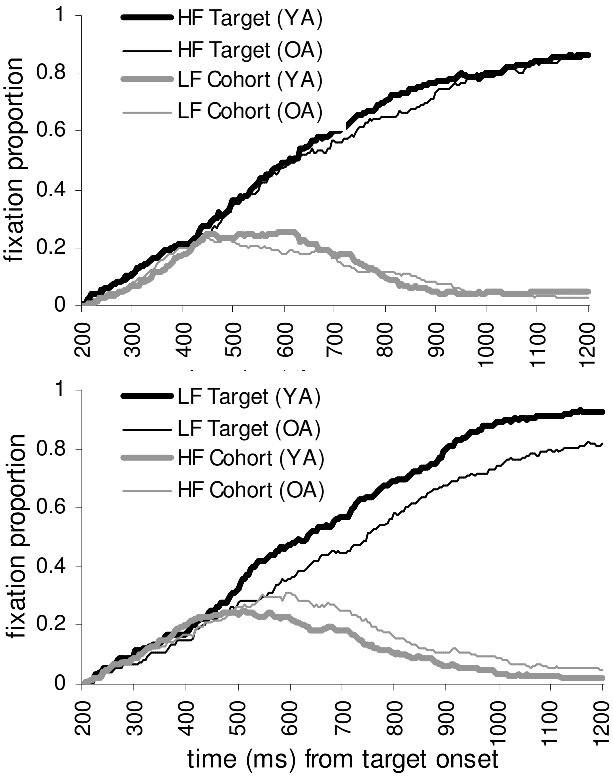

Figure 1: Fixation proportion curves

Table 1: Growth Curve Analysis

	Model	-2LL	ΔD	*p* <
High Frequency Target	Base	118710.2	--	
	Age * Intercept	118709.9	0.3	n.s.
	Age * Slope	118709.5	0.4	n.s.
Low Frequency Target	Base	120321.3	--	
	Age * Intercept	120312.3	9.0	**0.05**
	Age * Slope	120310.7	1.6	n.s.

target fixation curves (Figure 1, bottom panel). Older adults show significantly less activation of the target, as evidenced by an improvement in model fit when Age is added to the linear term.

Turning to the pattern of fixations on competitors, the form of the competitor activation curve is less suited to simple growth curve analysis. We have no strong parametric function for modeling these curves and a nonparametric polynomial function is less well suited to the form of the competitor fixation curves. Specifically, these functions often generate large residuals near the ends of the functions. Instead, we calculated a relatively simple measure corresponding to the amount of time spent fixating the competitor (equivalent to the area under the curve) for each subject in both frequency conditions. Again, young and older adults fixated the competitor equally often when the cohort was low frequency [t (30) = 0.73, p > 0.1]. However, older listeners spent more time relative to younger listeners looking at the cohort competitor when it was high frequency [t (30) = 2.01, p = 0.053].

The results suggest that when competition is low, older and younger listeners have equivalent time courses for spoken word processing. However, when spoken word recognition is made more difficult (here, by high frequency cohort competition), older adults show evidence of increased activation of the competitor and decreased activation of the target word.

TRACE Modeling of Empirical Results

To better understand the mechanisms that might lead to older listeners' increased susceptibility to competition, we used an implemented model of spoken word recognition, TRACE (McClelland & Elman, 1986; Strauss et al., 2007), to capture the pattern of age differences. Although the implemented version of TRACE has a large number of parameters, we can distinguish between those parameters that have explanatory power and those that are merely implementational. We focus on four parameters that are reasonable candidates for attempting to capture age differences based on prior research.

We have noted that age-related hearing loss (presbycusis) is common in individuals over the age of 65 and mild hearing difficulty is likely experienced by our older adults despite their self-report of good hearing abilities and highly accurate performance in the experimental task. External noise is often used with young adult subjects to degrade their performance to older adult levels in speech processing tasks. Similarly, within the model we can degrade the quality of input to the model by injecting noise into the model's input representations.

The notion that increasing age results in a generalized increase in internal noise is also one that has a long history in cognitive aging (Myerson et al., 1990; Welford, 1981). We can increase the amount of internal noise by injecting random normally distributed noise to the inputs to units at each level of the model.

Theories in cognitive aging have long focused on the seeming difficulty that older adults have in selecting between competing representations during processing (Hasher & Zacks, 1988). We have also noted that in language production, lexical level competition is particularly age-sensitive. In spoken word recognition, the disadvantage for 'difficult' words from high density neighborhoods in the Sommers and Danielson studies (1999) was attributed to inhibitory deficits. We can specifically influence competition between representations by reducing the within-level reciprocal inhibitory connections.

Finally, there is some evidence in visual word recognition that frequency may actually exert a greater influence on processing in older compared to younger adults (Spieler & Balota, 2000). Here, we can allow the frequency sensitive weights between the phoneme and word layer to take on a broader distribution, resulting in a magnification of the influence of frequency on recognition.

Methods

We use a recent reimplementation of the TRACE model (jTRACE; Strauss et al., 2007) to examine whether any of these four parameters may capture age-related differences seen in the eyetracking data from our young and older adults. Following others, we link lexical activation levels to fixation proportion-like response probabilities using the Luce choice rule (for a more complete explanation of the linking hypothesis between eye movement data and TRACE activations, see Allopenna et al., 1998).

Parsimony is our guiding principle in the attempt to model the effect of age in these data. Rather than seeking the best fit with a combination of these parameters, we ask whether parametric variations in any of these single parameters give results that leave the high frequency target/low frequency competitor pattern relatively unaffected while showing increased cohort competition for the low frequency target/high frequency competitor condition. To adequately capture the age differences in the empirical data, we would like to see very modest changes in fixation probabilities for high frequency targets and low frequency competitors. In contrast, for low frequency targets and high frequency competitors, we look for an increased maximum fixation probability for the competitor and continued greater fixation probabilities for the competitor throughout the trial.

For the frequency simulation, all other model parameters were set to the default levels (Strauss et al., 2007). In order to include an effect of lexical frequency in the external noise, internal noise, and inhibition simulations, the weights was set to and held at the value of 0.13 recommended by Dahan et al (2001). See Table 2 for the values of the manipulated parameters used in the simulations. The original 201-word lexicon included with TRACE was used for all simulations. We selected a set of four words (dip → "deep", did → "deed", rul → "rule", trat → "trait") with phonological and frequency properties comparable to our

Table 2: TRACE Parameters

Parameter	Min : Step Size : Max
NoiseSD (input noise)	0 : 0.2 : 0.6
StochasticitySD (internal noise)	0 : 0.005 : 0.3
Gamma.W (word-layer inhibition)	0.1 : 0.005 : 0.3
Frq Wts P-W (frequency)	0.13 : 0.03 : 0.22

experimental stimuli. Each parameter value was tested with the high frequency target (dip) and the low frequency target (did). Since the internal noise (stochasticitySD) parameter makes TRACE output nondeterministic, the data from fifteen runs of the simulation at each frequency level (the same as the number of trials per condition in our study) were averaged together.

Results

All of the parameters tested resulted in orderly changes in the target and competitor fixation probability functions. Although degradation of the input and internal noise are theoretically distinct influences, adding noise to the input and adding noise to all layers of the model had similar effects overall, though adding internal noise does increase the variability in the model's output since it makes the output of TRACE nondeterministic. The noise simulations fail to capture the salient features of the data. Specifically, increased noise lowers the peak of the competitor activation curve regardless of competitor frequency (Figure 2 a and b).

When the strength of the inhibitory connections within the word layer is decreased, the asymptotic height of the target activation curve decreases as competition from the cohort competitor exerts an influence over a longer period of time (Figure 2 c and d). This effect is more pronounced for low frequency targets and high frequency competitors, as seen in our data. However, there remains a relatively large effect on the high frequency target fixations that is not present in the data. This occurs because the reduced competition allows the initially modest activation of the low frequency competitor to continue to collect fixations throughout processing. The empirical data does not appear to show such continued competition when the target is high frequency.

Increasing the influence of frequency on the phoneme to word connections captures some salient aspects of the empirical results (Figure 2 e and f). Note that when the target is a high frequency word, increasing the influence of frequency facilitates the target fixations and there are smaller changes in fixations on the low frequency competitor. In the empirical data, older listeners do not show a *faster* time course for target fixations. However, given the ubiquitousness of age differences in overall processing speed, the lack of any age difference for high frequency targets may be consistent with some facilitation in this condition counteracted by general age differences in processing speed. More importantly, note that for high frequency competitors, the height of the fixation curve is increased, and this difference is preserved throughout processing.

Across these parameters, we would argue that an increased influence of frequency is the most consistent with the empirical results. Of course, aging is a relatively global factor that we would not necessarily expect to selectively influence only a single parameter. Nonetheless, we would suggest that an increased influence of frequency, similar to that seen in visual word recognition, provides a relatively parsimonious account for the empirical age differences.

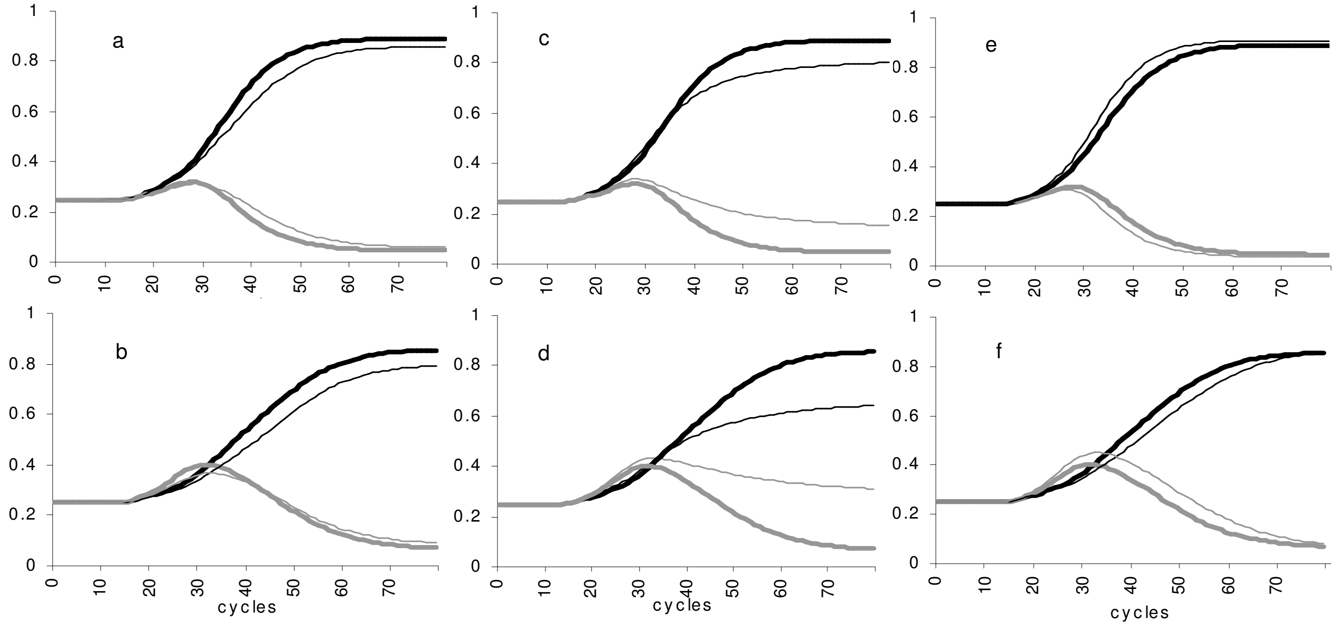

Figure 2: TRACE simulations. Panels a, c, and e show HF targets, LF cohorts; panels b, d, and f show LF targets, HF cohorts.

General Discussion

In the experiment and simulations described above we found that older adults were differentially affected by high competition demands, which resulted in fewer fixations to a low frequency target and increased fixations to a high frequency phonological competitor. However, the time course of lexical activation in young and older adults is quite similar when competition demands are low. These data are consistent with previous research indicating that older adults have a harder time than young adults do identifying 'difficult' words with many phonological competitors (Sommers, 1996; Sommers & Danielson, 1999), though the task used here (following spoken instructions) is more naturalistic than the overt word identification responses used in previous research. In addition, the eyetracking data lends itself to comparisons with transformed lexical activations from the TRACE model of speech processing and spoken word recognition (Allopenna et al., 1998). Consistent with the visual word processing literature we find that a parameter that affects the strength of lexical frequency effects captures some of the salient properties of our dataset.

Cognitive aging research is often complicated by the fact that older adults generally respond more slowly than young adults in almost any task, necessitating that some sort of correction be made to equate performance in the baseline condition. This is often accomplished by varying the task difficulty for young and older adults or by scaling the resulting data, both of which can complicate interpretation of the results. While mouse click reaction times were indeed slower for older adults across the experiment, the fixation proportion curves arising from the eye movement data did not significantly differ with age when competition demands were low. Since no data scaling is necessary to equate older and younger adult performance in this condition, we do not have to manipulate the data in the high competition condition where we do observe an age difference. The results shown here are consistent with the results of other studies of age-related change in spoken word recognition using different methodologies but do not require the task or data manipulations required by other techniques. Furthermore, an existing implemented model of adult spoken word recognition allows researchers to explore the effects of possible explanatory mechanisms. This indicates that the visual world paradigm can be an important and informative tool for studying age differences in language processing.

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