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The Effect of Lexical Frequency on Spoken Word Recognition in Young and Older Listeners

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Abstract

When identifying spoken words, older listeners may have difficulty resolving lexical competition or may place a greater weight on factors like lexical frequency. To obtain information about age differences in the time course of spoken word recognition, young and older adults' eye movements were monitored as they followed spoken instructions to click on objects displayed on a computer screen. Older listeners were more likely than younger listeners to fixate high-frequency displayed phonological competitors. However, degradation of auditory quality in younger listeners does not reproduce this result. These data are most consistent with an increased role for lexical frequency with age.

Keywords

spoken word recognition; lexical frequency; eyetracking; visual world paradigm

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. This is true even when their hearing is relatively preserved or when stimulus or task demands are manipulated to equate younger and older adult baseline performance (Sommers, 1996; Sommers & Danielson, 1999; Taler, Aaron, Steinmetz & Pisoni, 2010; Wingfield, Aberdeen & Stine, 1991). For example, when younger adults and older adults with good hearing were asked to identify sentence-final words in a gating experiment, older adults needed to hear slightly more of a word before they were able to correctly identify it in neutral contexts (Wingfield et al., 1991). This study emphasizes the important point that, unlike printed text, the information critical for identifying spoken words is distributed across time. In the present paper, our focus is on the moments surrounding the arrival of acoustic information during the recognition of individual spoken words and in particular, how age impacts the process of selecting between lexical candidates during successful spoken word recognition.

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Competition During Spoken Word Recognition

In most theoretical accounts of spoken word recognition, listeners activate a set of candidate words that are consistent with the transiently available speech stream and winnow down this set of words as more information from the unfolding utterance becomes available. Thus, the process of spoken word recognition depends on successful resolution of the competition for activation between candidate words (Luce & Pisoni, 1998; Marslen-Wilson, 1987). One area where older adults appear to have particular difficulty is in resolving lexical competition during spoken word recognition. Sommers and colleagues (Sommers, 1996; Sommers & Danielson, 1999) asked younger and older participants to identify words embedded in noise. These words varied in terms of the composition of their lexical 'neighborhoods'; that is, the set of words phonologically similar to the target word through the addition, deletion, or substitution of a single phoneme. In these studies, older listeners had more difficulty than younger listeners identifying 'hard' words, that is, words with many and relatively frequent neighbors, than 'easy' words with fewer, less frequent neighbors. This was true even when the noise level was manipulated to equate performance on the easy group of words for both age groups. One possibility is that the process of gradually winnowing down the set of candidate words is less efficient in older listeners, so that words that are partially activated by the initial phonemes of the target are more difficult for older listeners to inhibit and remain highly active. This account links changes in lexical competition to changes in inhibitory abilities often cited as a problem in aging (Hasher & Zacks, 1988; Sommers, 1996; Sommers & Danielson, 1999; Taler et al., 2010).

Another possible contributor to the difficulty older listeners have resolving competition during spoken word recognition is changes in the use of lexical frequency information. In visual word processing, older readers show larger influences of lexical frequency than do younger readers (e.g., Balota, Cortese, Sargent-Marshall & Yapp, 2004; Spieler & Balota, 2000)[1]. Lexical frequency is also known to influence spoken word recognition, with high frequency words being identified more quickly and more accurately than low frequency words (Goldinger, Luce & Pisoni, 1989, Howes, 1957; Marslen-Wilson, 1987), especially when the stimulus is degraded or listening conditions are demanding. An increased reliance on lexical frequency in older listeners, who may experience a variety of perceptual challenges in listening, would also be broadly consistent with a Bayesian perspective on word recognition where prior information about a word's likelihood becomes more important when the input is degraded or ambiguous (Norris & McQueen, 2008).

Visual World Paradigm

While it is common to use a final product of spoken word recognition such as word identification accuracy to infer differences in the processing of spoken words, spoken word recognition is in fact a dynamic process (Dahan & Gaskell, 2007). One useful research tool for exploring competition dynamics in spoken word recognition is the *visual world paradigm*, where participants follow spoken instructions to interact with objects or pictures in the visual environment. Participants generate eye movements to the available referents that are closely time-locked to the unfolding speech signal and can be used as an index of lexical activation and competition between the referents across time with an explicit linking hypothesis where the probability of fixating an object at a given time is related to the activation of that word relative to the activations of the other potential targets (Allopenna,

[1]The literature is not unanimous in suggesting an age-related increase in word frequency effects in visual word recognition (Allen, Madden, & Crozier, 1991; Allen, Madden, Weber, & Groth, 1993; Bowles & Poon, 1981; Tainturier, Tremblay, & Lecours, 1989). However, we suggest the large scale studies (Balota et al., 2004, Spieler & Balota, 2000) provide a better characterization of the role of word frequency. These large scale studies are concerned with the proportion of variance accounted for by frequency rather than the size of mean RT differences across categorically represented factors (e.g., high versus low frequency). We suggest that the former more directly addresses the question of the role of frequency in processing.

Magnuson & Tanenhaus, 1998). Most empirical evidence for age differences in spoken word recognition is based on how stimulus manipulations influence the final product of recognition, with substantial error rates often induced by making listening conditions difficult or unnatural. Here, we are able to observe the dynamics of successful competition resolution under relatively natural listening conditions. In addition, many of the experimental tasks used in the examination of age differences in spoken word recognition impose secondary demands on participants (for example, planning and executing a button push or a spoken response) which 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, making the visual world paradigm especially useful for sensitive groups such as healthy and language-impaired children (McMurray, Samelson, Lee & Tomblin, 2010) and healthy older adults and aphasics (Ben-David et al., in press; Yee, Blumstein & Sedivy, 2008).

While previous studies have demonstrated that non-displayed lexical competitors and the structure of the entire competitive environment, including factors like frequency-weighted neighborhood density, have consequences for processing in the visual world paradigm (Magnuson, Dixon, Tanenhaus & Aslin, 2007; Revill, Tanenhaus & Aslin, 2008), effects arising from the characteristics of displayed competitors are larger and more readily observable and thus may be most appropriate for initial uses of the visual world paradigm with older participants. For this reason, we focus on the effects of the lexical frequency difference between displayed targets and phonological competitors rather than the structure of the entire phonological neighborhood. Dynamic, long-lasting effects of target word frequency as well as lexical frequency differences between the target and displayed phonological competitors can be readily observed in the visual world paradigm (Dahan & Gaskell, 2007; Dahan, Magnuson & Tanenhaus, 2001; Magnuson et al., 2007).

In the present paper, we use the visual world paradigm to examine differences in how lexical frequency affects lexical activation and competition over time in younger and older adults when secondary task demands are low and final accuracy is high. Whether older adults weight lexical frequency information more heavily or have problems inhibiting competition from activated competitors, older adults should show an increase in the probability of fixating high frequency competitors. However, lexical frequency-based accounts also predict that older adults will demonstrate an advantage for high frequency target words while showing less competition from low frequency competitors. In contrast, a deficiency in inhibiting activated competitors should lead to a pervasive increase in susceptibility to competition in older listeners, with the difference accentuated for high frequency competitors with more activation to inhibit.

Experiment 1

Participants—Sixteen young adults (ages 18–22, mean 19.5, 8 female) and 16 community-dwelling older adults (ages 60–78, mean 73.1, 6 female) were recruited from Georgia Tech and the surrounding community. All were native English speakers with normal or corrected-to-normal vision, self-reported good hearing, and no history of neurological disease. As is often the case, the older adults had significantly higher WAIS Vocabulary subtest scores (Weschler, 1997) than the younger adults; M_{old} = 49.0, M_{young} = 38.3, $t(30) = 5.08$, $p < 0.01$. All 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 onset-overlapping, or cohort, competitors were selected as critical stimuli. Twelve pairs consisted of monosyllabic words that differed only at the final consonant (or consonant cluster), and three pairs consisted of bisyllabic words with overlapping first syllables. One member of each pair had a relatively low frequency (mean 11.1/million, range 1–42/million) and one had a relatively high frequency (110.9/million, range 27–269/million) according to the CELEX English database (Baayen, Piepenbrock & van Rijn, 1993). Although the lowest high frequency words and the highest low frequency words had similar frequencies, within a given cohort pair the high frequency word was at least 25/million more likely than the low frequency word (mean difference 99.7/million, range 25–227/million). An additional fifty frequency-matched words were targets on filler trials. Matching pictures for all target words 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 normed set for use as distracters on critical and 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. The average point of disambiguation between the target and competitor words occurred 327 ms after word onset.

Procedure—Each participant completed a single 30-minute experimental session consisting of 100 trials: twenty practice trials, thirty critical trials and fifty filler trials. Participants were seated approximately 60 cm in front of a computer monitor and were told that on each trial, they would see four objects appear on the screen. Spoken instructions would instruct them to click on one of the four objects. All auditory stimuli were presented over Sennheiser HD 280 Pro headphones at 80 dB SPL. Participants were asked if they wished to adjust the stimulus volume during the practice block to achieve a more comfortable listening level, however, all participants deemed the volume appropriate and declined to make changes.

Eye movements were monitored using an EyeLink head-mounted eyetracker sampling at 250 Hz, 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 calibration. Four pictures, each spanning approximately 5 degrees of visual angle, appeared on the screen in compass point positions at an equal distance from the fixation cross. The spoken instruction began 500 ms after the pictures appeared. Participants then clicked on the named picture. Both eye movement and mouse response data were collected. Saccade onsets and offsets were automatically identified using the tracker’s acceleration, velocity and distance criteria. Screen coordinates between the offset of one saccade and the start of the next were averaged to give the fixation location, which was classified as a fixation to an object if it fell into the 5 degree region of interest around each picture or as a ‘blank’ fixation (a fixation outside any picture’s region of interest). For analysis purposes, the duration of the fixation began at the onset of the saccade to the region of interest to account for attentional shifts preceding eye movement.

After twenty practice trials, the remaining eighty trials were presented in a different pseudo-random order to each participant with critical and filler trials intermixed. In critical trials, two cohort competitors and two phonologically unrelated distracter items were present. 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. To avoid generating expectations that phonologically similar words were always target-relevant, additional cohort pairs were also present as (unnamed) distracter objects on 40% of filler trials. Furthermore, 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.

Analysis—In general, eyetracking studies of spoken word recognition examine how average fixation proportions to certain categories of displayed objects change over time (Allopenna et al., 1998; Dahan, Magnuson & Tanenhaus, 2001) or how many saccades are launched to certain categories of displayed objects during a particular time window (Dahan & Gaskell, 2007). Here, we focus on the former, plotting the average probability across trials of fixating target, competitor, and distracter objects over the time course of the trial. We analyze the properties of the fixation probability time course curves using latent growth curve analyses (Mirman, Dixon & Magnuson, 2008). Doing so, we avoid a number of problems associated with time-bin analysis methods (including violations of ANOVA assumptions, see Barr, 2008; Mirman et al., 2008). The analyses are hierarchical and involve fitting a polynomial function to individual subjects' data and testing the effects of explanatory variables (like age or condition) at a second level of analysis to determine whether those variables improve the fit of the functions. Following Mirman and colleagues (Mirman et al., 2008) we use an orthogonal cubic function to fit fixation proportion curves for named (target) objects, and quartic functions to fit fixation proportion curves for phonologically-related competitor objects. We test whether adding parameters to the model significantly improve the fit by examining the deviance statistic (-2 * log likelihood), which is distributed as chi-square with degrees of freedom equal to the number of parameters added (Singer & Willett, 2003).

Results & Discussion

A two-way ANOVA on arcsine-transformed accuracy for the critical trials with age group as a between-subjects factor and target word frequency as a within-subjects factor showed significant main effects of frequency, $F(1,30) = 5.4$, $p < 0.05$, and age, $F(1,30) = 5.6$, $p < 0.05$, but no interaction ($F < 1$) While both groups were less likely to select the correct low frequency target (96.5%) than the high frequency target (98.3%) and older adults were less likely to select the correct target than the younger adults (96.0% vs. 98.8%), all participants were still highly accurate, clicking on the named object on more than 95% of critical and filler trials. The time it took to click on the picture (relative to the onset of the target word) was also affected by age and frequency. A two-way ANOVA showed significant effects of age ($F(1,30) = 32.1$, $p < 0.01$) and frequency ($F(1,30) = 34.4$, $p < 0.01$) as well as a significant interaction ($F(1,30) = 9.1$, $p < 0.01$). Both young and older adults were faster to click on high frequency (young: 1292 ms, old: 1652 ms) than low frequency targets (young: 1378 ms, old: 1920 ms), but the high frequency advantage was larger for the older adults.

As the focus of this study is on the time course of competition in successful spoken word recognition, fixation proportion curves were created by averaging across all correct trials for each subject at each level of frequency (Figure 1a, b). Target and competitor fixation curves were of different functional forms and were subjected to separate growth curve analyses. Fixation curves for phonologically unrelated distracter items were relatively flat and did not rise above 10% fixation probability during the measured time windows. Despite baseline differences in the time it took young and older participants to click on the target picture, fixation proportion curves showed a remarkably similar overall timecourse for both groups.

Shown in Figure 2a is the proportion of competitor fixations for the younger and older adults as a function of time. We analyze competitor fixations beginning 200 ms after the target word onset up to 1000 ms after the target word onset. Fixations before 200 ms are unlikely to be influenced by target word information (Hallett, 1986). Fixations after 1000 ms, approximately 300 ms after word offset and 600 ms after the point of disambiguation between the targets and competitors, are less likely to be directly linked to word recognition and more likely to be influenced by processes tied to response-related motor planning and production. After 1000ms, cohort fixation proportion curves are below 10% and are indistinguishable from distracter fixation proportion curves. As in previous research, competitor fixation proportion rises during the initial, ambiguous proportion of the spoken word and then gradually declines after disambiguating information is available. This pattern is seen for all participants regardless of age or the frequencies of the competitor words, though an age-related difference in frequency effects can be clearly seen. We fit two quartic functions (high and low frequency) to each individual's cohort competitor fixation data. While allowing competitor height and quadratic curvature parameters to differ for the lexical frequency categories improves the fit of the level 2 model ($\Delta D = 10.7$, $p < 0.01$), there was no main effect of age on the height or the curvature of the fitted function to suggest an overall increase in competition in older adults ($\Delta D = 0.8$, $p > 0.1$) as predicted by an inhibitory deficit account. However, allowing age and frequency terms to interact in the level 2 model significantly improves the fit, $\Delta D = 21.9$, $p < 0.05$. To further investigate this interaction, we tested the effect of age for high and low frequency competitors separately. At each frequency level, allowing competitor height and curvature parameters to vary with age group improves model fit, indicating that older listeners show increased activation of high frequency competitors ($\Delta D = 26.2$, $p < 0.01$) and reduced activation of low frequency competitors ($\Delta D = 22.0$, $p < 0.01$) compared to younger listeners. While older adults show a robust frequency difference in cohort competitor fixations ($\Delta D = 16.8$, $p < 0.01$), younger adult listeners do not ($\Delta D = 1.4$, $p > 0.1$).

Although the competitor curves provide the strongest test of inhibitory and frequency-based predictions for older adults' changes in lexical competition during spoken word recognition, target fixations can also be examined for the effects of age and lexical frequency. Consistent with previous eyetracking studies of spoken word recognition, target fixation proportions gradually increase during and immediately after the utterance as participants fixate the object in preparation to click on it. Cubic functions were used to fit target fixation curves from 200 to 1200 ms, a time point after which the curves have reached asymptote but before either group has made a mouse click response. The addition of frequency or age terms to the second level model affects the fit of the model to the target fixation curves differently. As is apparent in Figure 1c, high frequency words have higher fixation probabilities across time than low frequency words. Allowing frequency to enter the second level of the model improves the fit of the model by shifting the height of the curve based on the frequency of the target, $\Delta D = 14.8$, $p < 0.01$. Allowing age to affect the curve's slope (linear coefficient) also improves the fit of the model, $\Delta D = 13.0$, $p < 0.01$, suggesting slightly slower target activation for older adults. While there is a trend for a larger frequency effect for older compared to younger listeners, the interaction for the target fixation proportions did not reach significance ($\Delta D = 3.7$, $p > 0.05$). Planned comparisons reveal that allowing age to enter the model only affects the model fit for the high frequency targets ($\Delta D = 12.3$, $p > 0.01$) but not for the low frequency targets ($\Delta D = 3.1$, $p > 0.05$).

While difficulties inhibiting active competitors should slow target activation in both frequency conditions, an increase in the influence of lexical frequency predicts a benefit for high frequency items, including high frequency targets, for older listeners. Older listeners show a larger difference in fixation proportions to high frequency targets and low frequency competitors than younger listeners (Fig 1a) and an initially larger difference in fixation proportions to high frequency cohorts and low frequency targets (Fig 1b). Close inspection of Figure 1c also supports this prediction, showing initially higher fixation proportions for older listeners than younger listeners when the target is high frequency. A post-hoc analysis of the area under the curve from word onset until the average point of disambiguation for the cohort pairs (0–325 ms, shifted by 200 ms to account for saccadic delay) reveals that older listeners have higher fixation proportions for high frequency targets than younger listeners during this early time window, $t(30) = 2.50$, $p < 0.05$. The target data does not fully replicate the effects seen in the cohort competitor curves, however, since older adults do not show lower fixation proportions than the younger adults for the low frequency targets over the same window, $t(30) = 0.43$, $p > 0.1$. However, the high frequency advantage for older adults is also apparent when high frequency items (whether target or cohort) are compared to low frequency items (whether target or cohort) in that ambiguous interval (Fig 1d), with older listeners showing a significantly greater high frequency advantage score (average fixation proportion difference for HF and LF item from 200–525ms after target onset, mean = 0.078) than younger listeners (mean = 0.012), $t(30) = 2.57$, $p < 0.05$.

The pattern of results described above do not suggest overall increased competition resulting from a failure to inhibit active competitors but provide some support for an increased role for lexical frequency information during spoken word recognition. Bayesian models of spoken word recognition (Norris & McQueen, 2008) predict that degraded sensory input should result in larger effects of lexical frequency (a key component of a word's prior probability) when the sensory input is more ambiguous. While the older listeners described above did not have clinically diagnosed hearing loss and identified their hearing as relatively good, it is possible that sub-clinical changes in hearing sensitivity are influencing their performance, given that peripheral changes in sensory acuity can influence the performance of older adults in a wide range of situations (McCoy et al., 2005; Pichora-Fuller, Schneider & Daneman, 1995; Pichora-Fuller & Souza, 2003). Although we were unable to obtain hearing acuity measures from these participants, when we measure the pure-tone thresholds of older adults drawn from the same pool of participants as those from this experiment, we find hearing thresholds below 25dB HL at 1–2 kHz but slightly elevated thresholds above that frequency (on average, 29dB HL at 4kHz), while our younger adults are below 25dB HL at all measured frequencies. The question is whether subtle degradations in the quality of the acoustic input can increase the reliance on word frequency in a such a way as to drive a temporary advantage for high frequency candidates even when that competition is later successfully resolved. There is some evidence that subjecting young adults to spatially or temporally degraded stimuli in tasks driven by bottom-up information does move their word identification performance closer to the performance of older adults (Pichora-Fuller, Schneider, MacDonald, Pass & Brown, 2007), at least when top-down contextual support is not readily available (Pichora-Fuller, 2008). If advantages for high frequency words result simply from degraded perceptual input available to the older listeners, then it should be possible to produce similar effects by temporarily degrading the auditory input to younger listeners.

Experiment 1b

To address this possibility, we tested an additional group of sixteen young adults (ages 18–25, mean 20.0, 8 female) using degraded stimuli to determine whether peripheral degradation alone can increase reliance on lexical frequency. WAIS Vocabulary scores did not differ from the previous group of young adults ($M_{noisy} = 40.4$, $t(30) = 1.0$, $p > 0.1$). White noise was added to the stimuli described above using the 'Sound' package available for R (R Development Core Team, 2009). The noise was normalized to 20% of the peak amplitude of the stimulus and was present throughout the carrier phrase and target word. All other materials and procedures were identical to those described above. It is important to note that the stimulus degradation is not specifically designed to mimic the type of peripheral or central declines in auditory acuity experienced by older adults but simply to test Bayesian predictions about whether degrading the speech stimulus for young adults also results in increased competition from high frequency competitors during lexical processing. No model of spoken word recognition predicts that only specific types of degradation will increase reliance on top-down information like lexical frequency.

Results & Discussion

Overall, participants were more likely to correctly select a high frequency target (94.2%) than a low frequency target (90.4%), while the young adults who heard degraded stimuli were less likely to select the correct item than the younger adults who heard undistorted stimuli (85.8% vs. 98.8%). An ANOVA on the young adult accuracy performance with frequency as a within-subject factor and stimulus clarity as a between-subjects factor showed a significant main effect of stimulus clarity, $F(1, 60) = 126.4$, $p < 0.001$, and a significant main effect of frequency, $F(1, 60) = 6.8$, $p < 0.05$, but no interaction ($F < 1$.) The degradation manipulation was effective in significantly reducing young listeners' final word identification performance. However, young listeners presented with degraded stimuli do not show enhanced competition from high frequency cohort competitors during the time course of spoken word recognition as the older listeners do. We show competitor fixation proportions for both groups of young listeners in Figure 2b. Overall, stimulus degradation slightly reduces the probability of fixating a cohort regardless of frequency, which is reflected in the model by a significant increase in fit when stimulus clarity (clear vs. degraded) is added to the quadratic term of the model, $\Delta D = 4.0$, $p < 0.05$. However, no significant fit improvements are seen when frequency is allowed to interact with stimulus clarity. This contrasts with the pattern observed for older listeners, where age had little overall effect but significantly interacted with frequency. This suggests that peripheral stimulus degradation alone is not sufficient to explain older adults' enhanced competition from high frequency competitors. When young adults with good hearing are presented with stimuli degraded with noise, their word identification performance (as measured by clicks on the correct picture) declines, but competition from a high frequency cohort competitor (as indexed by the proportion of fixations allocated to cohort pictures) does not increase as it did for the older adults. The data from the young listeners suggest that temporary and purely peripheral degradation does not result in an increased role for word frequency during the resolution of lexical competition, so possible peripheral hearing loss in the older adult participants is not alone a satisfactory explanation of the temporary increase in competition from high frequency cohort competitors.

General Discussion

We found that lexical frequency differentially affected lexical competition in younger and older listeners, as shown by older listeners' evidence for increased activation of high frequency targets and cohort competitors and reduced competition from low frequency competitors. While inhibitory deficits may explain some of the difficulty older adults have in overcoming competition from strong competitors during spoken word recognition (Sommers & Danielson, 1999; Taler et al., 2010), the benefit for older listeners when target frequencies were high but competitor frequencies were low is more problematic.

We suggest as an alternative that the recognition process in older listeners is more tuned to the use of word frequency information during recognition. There is consistent evidence that word frequency is more predictive of older adults' performance in visual word processing (Balota et al., 2004; Rayner, Reichle, Stroud, Williams & Pollatsek, 2006; Spieler & Balota, 2000). In spoken word recognition, reduced reliability in the input also provides an opening for the increased role of frequency in resolving competition. Certainly this increased role of frequency can be seen in the Bayesian models proposed by Norris and McQueen (2008). However, when Norris and McQueen test a symmetrical version of this effect (they improve rather than degrade the perceptual input to their model) the influence of perceptual quality is largely in the asymptotic level of performance (Figure 5, Norris & McQueen, 2008). This is similar to what is seen for the young adults who heard degraded stimuli in Experiment 1b but quite different from what we observe in the older adult listeners, where greater competition from a high frequency competitor is seen during processing but is eventually resolved. In other words, the principle problem of the Bayesian account for interpreting our results is that the increased competition in older listeners has a relatively time-limited duration. However, there is an important caveat in that the Bayesian model is not a process model. That is, the availability of new perceptual inputs change the probability distribution over the set of candidate words, but the timing of such changes that must take place over some small amount of time occurs essentially instantaneously in the model. Thus, the more Spartan Bayesian account appears to flounder on the dynamic data that we suggest is the most interesting aspect of age differences in spoken word recognition.

While data from the young listeners suggest that temporary, purely peripheral degradation does not result in an increased role for word frequency during the successful resolution of lexical competition, older listeners have experienced a broad range of age-related changes that may shift processing in favor of word frequency. In particular, the temporal constraints on processing may make the readily available information about word frequency an extremely valuable source of evidence. In general Bayesian terms, anything that reduces the influence of the current perceptual input opens the door for an increase in the influence of word frequency. However, the degraded quality of the input need not be solely peripheral or even perceptual. For example, under conditions where semantic integration or discourse comprehension is slowed (Federmeier & Kutas, 2005; Federmeier, Van Petten, Schwartz & Kutas, 2003) it might be adaptive to increase the weight of frequency information that can be brought to bear on processing quickly. Prior knowledge of the frequency of particular words is likely to be information that can be used immediately in processing to allow older listeners to achieve sufficiently accurate and fast identification. This adaptation may take place slowly over time, occurring in lock step with age-related changes in processing. Thus, such adaptations are not likely to be strategic in the sense that they are consciously chosen and easily reversible. Future research will be needed to determine which aspects of age-related changes may be responsible for changing the nature of or shifting the weighting of lexical frequency representations in older adults as well as to understand the relative contributions of these factors as well as other factors like inhibitory deficits or cognitive/ perceptual effort tradeoffs.

In summary, we demonstrate that the resolution of lexical competition is influenced by frequency to a greater extent in older compared to younger listeners. This is consistent with greater reliance on frequency information with age. Importantly, we demonstrate this effect in measures of the time course of processing while secondary task demands are low and final accuracy is high.

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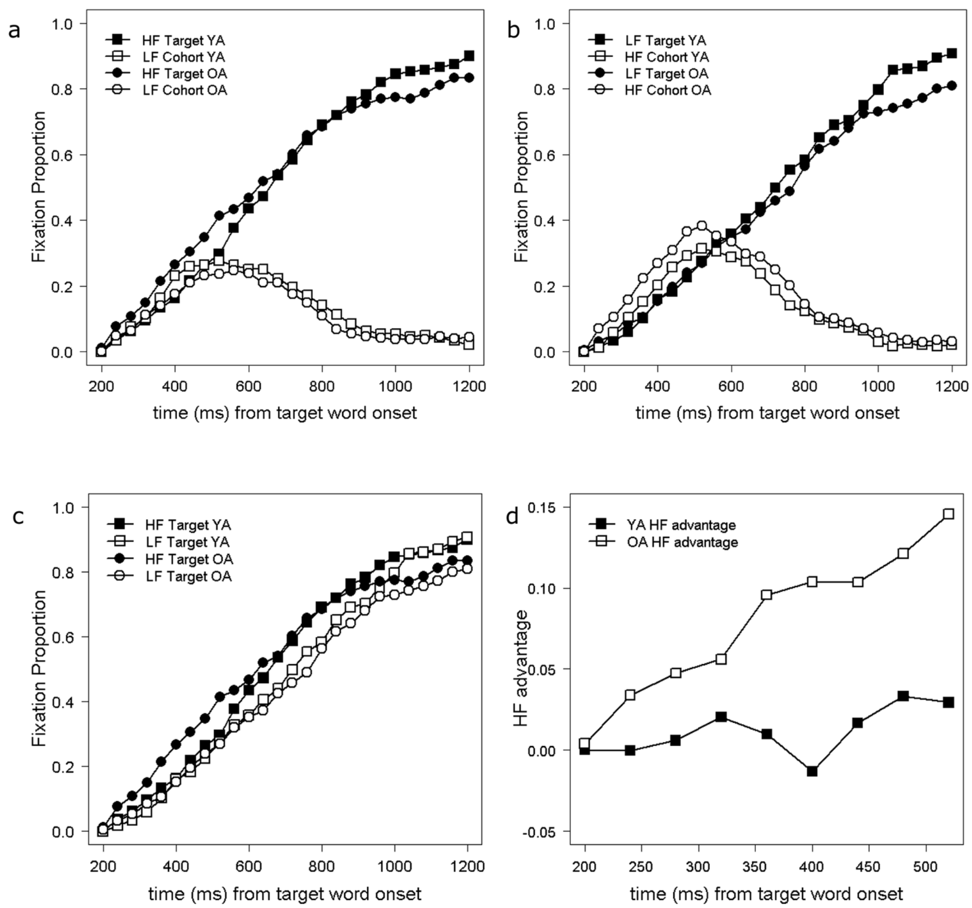

Figure 1.

Fixation proportions for target and competitor fixations for young and older listeners from 200–1200ms after the onset of the target word for (a) the HF target, LF competitor condition and (b) the LF target, HF competitor condition (distracter fixation proportions remained less than 0.1 and are not pictured.) (c) Proportion of target fixations for young and older listeners from 200–1200ms after the onset of the target word. (d) HF advantage (HF item – LF item, regardless of target/cohort status) in the phonologically ambiguous interval (0–325ms, shifted by 200ms to account for average fixation planning time).

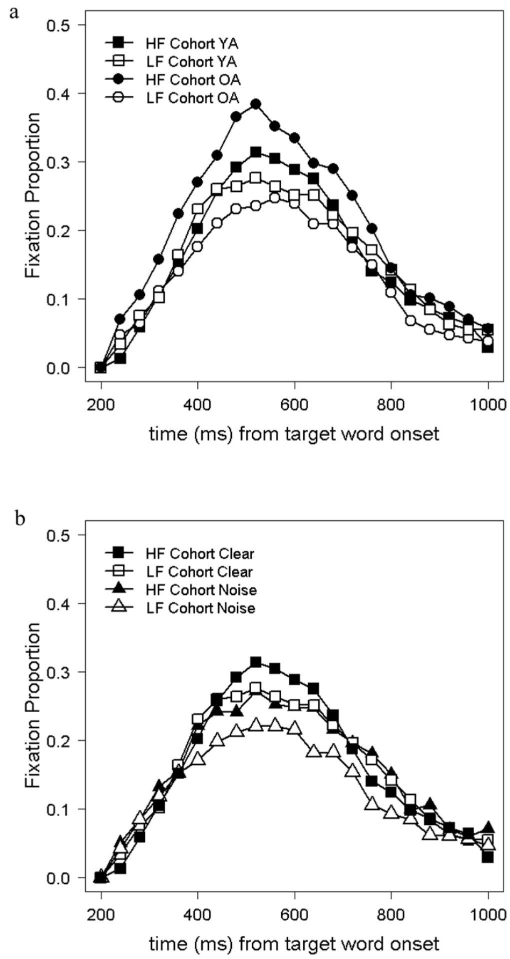

Figure 2.
Proportion of cohort competitor fixations for young and older listeners (a) and young listeners under clear or noisy listening conditions (b).