The Effect of Priming on Release From Informational Masking Is Equivalent for Younger and Older Adults

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Objective: Previous studies have shown that presenting younger listeners with all but the last word of a target anomalous sentence immediately before presenting the full sentence in a noisy background produces a greater release from masking when the masker is two-talker anomalous speech than when it is speech-spectrum noise, thereby demonstrating that an auditory prime can produce a release from informational masking. The purpose of this study was to investigate whether older adults could gain the same benefit from auditory primes as younger adults and what bottom-up auditory factors contribute to the advantage provided by auditory primes in releasing speech from informational masking.

Design: A total of 76 younger adults (university students) and 76 older adults (volunteers from the local community) participated in this study. All participants spoke English as a first language and had normal hearing below 4 kHz.

Results: In experiment 1, younger adults performed better in the presence of the speech masker, whereas older adults performed equivalently under both types of masking, but auditory priming produced an equivalent amount of release from informational masking in both younger and older adults. To examine the degree to which familiarity with the target talker's voice contributed to the priming effects observed in the first experiment, in experiment 2, we primed individuals with sentences that were spoken by the target talker but with lexical content that was unrelated to the target sentences. There was no release from informational masking for either age group. Next, to investigate the extent to which the release from informational masking in the first experiment was due to the amplitude envelope cues provided by the prime, in experiment 3, we noise vocoded the prime (using 3 bands) to remove semantic content while retaining some cues about the prime's amplitude envelope. When the primes were noise vocoded, there was no release from informational masking for either younger or older adults. Finally, to examine whether older adults' performance in the presence of the speech masker in the first experiment was due to an age-related decline in the ability to take advantage of dips in the amplitude envelope of the speech masker, in experiment 4, we noise vocoded the speech masker. We found a significant improvement in performance, but the amount of improvement was equivalent for both age groups.

Conclusions: Auditory priming resulted in equivalent amounts of release from informational masking in both younger and older adults. The benefit provided by auditory primes was not due to cues provided in the prime about the target talker's voice or cues provided in the prime about fluctuations in the amplitude envelope of the target sentences. Importantly, there was an age-related decline in performance in the presence of a two-talker masker relative to a continuous speech-spectrum noise masker; however, this age-related decline in performance cannot be attributed to age-related differences in the ability to take advantage of fluctuations in the amplitude envelope of the speech masker.

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INTRODUCTION

The ability to comprehend spoken language when there are other talkers will depend not only on the listener's ability to extract the target speech signal from the background but also on her or his ability to suppress or inhibit higher-order processing of the information conveyed by the competing talkers. All simultaneously presented sources with overlapping spectra will produce some degree of peripheral or energetic masking, thereby interfering with the extraction of the target speech signal. In addition, competing sound sources, such as other people talking, are also likely to interfere with the processing of speech at more central levels. Specifically, competing speech could elicit phonemic, semantic, and linguistic processing that could interfere with the processing of the target speech signal. Such interference is often referred to as informational masking (Freyman et al. 2004; Li et al. 2004; Schneider et al. 2007). Informational masking thus exerts its influence at a more cognitive level, making it difficult to identify and attend to the target, whereas energetic masking mainly operates at a sensory level, making it difficult to extract the signal from the background. Hence, the relative contributions of energetic and informational masking to speech understanding difficulties will likely differ depending on the nature of the competing sound sources, with the interference from a steady state noise being primarily energetic, whereas competing speech, in addition to energetically masking the target speech signal, is likely to produce a significant amount of informational masking.

Factors Providing Release from Informational Masking

Any factor that facilitates the perceptual segregation (Bregman 1990) of the target speech from competing speech is likely to enhance the abilities of listeners to focus their attention on the target speech and suppress or inhibit any phonemic, semantic, or linguistic interference elicited by the speech of competing talkers. At a peripheral level, the more two sources differ in regard to their spectral, temporal, and spatial properties, the more likely it is that bottom-up processing of the two sound sources will result in their perceptual segregation (for a review, see Bregman 1990). At a more central or cognitive level, factors such as familiarity with a talker's voice (Brungart et al. 2001; Newman & Evers 2007; Yang et al. 2007; Huang et al. 2010), knowledge of the target talker's identity (Yonan & Sommers 2000; Newman & Evers 2007), and knowledge of a source's location (Kidd et al. 2005; Singh et al. 2008) have been shown to operate in a top-down (knowledge driven) fashion to facilitate source segregation. Hence, in everyday listening situations, both bottom-up and top-down processes are likely to facilitate sound segregation when listeners are and top-down factors can provide a significant amount of release from informational masking in young adult listeners. However, much less is known about the effectiveness of these factors in facilitating release from informational masking in older adults.

Effects of Aging and Noise on Word Recognition

There are several reasons why older adults may be less able than younger adults to take advantage of bottom-up and/or top-down cues that would serve to enhance word recognition in noisy backgrounds. These include age-related declines in cognitive and auditory processing. At the cognitive level, the ability of older adults to process and understand speech may be hindered by declines in attention, working memory, inhibitory control, and general slowing (Cohen 1987; Hasher & Zacks 1988; Salthouse 1991; Wingfield & Stine-Morrow 2000). Reduced processing speed and a diminished working memory capacity could impede speech processing in general, and declines in the ability to focus and maintain attention could especially hamper speech understanding in situations where noise or multiple talkers are present (Anderson et al. 1998; Hogan et al. 2006; Levitt et al. 2006; Tun et al. 2009).

At the sensory level, the aging auditory system undergoes several changes that make it more vulnerable in complex listening situations. At the peripheral level, cochlear degeneration reduces temporal and spectral processing of auditory signals, likely resulting in degraded representations of signals at higher levels of the auditory nervous system (Schneider & Pichora-Fuller 2000; Pichora-Fuller 2003). In addition to impoverishing the auditory signal, sensory degradation in older adults and the resulting loss of acoustic information (Huang et al. 2009; Li et al. 2009) could also lead to less efficient source segregation (Huang et al. 2008) and, consequently, a smaller degree of release from informational masking. It is also possible that older adults might have to reallocate cognitive resources to compensate for poorer sensory input, thereby depleting the pool of resources available for language processing (for reviews see Schneider 1997; Schneider & Pichora-Fuller 2000; Schneider et al. 2007; Wingfield & Tun 2007; Schneider et al. 2010). Because the ability of older adults to benefit from cues differentiating competing sound sources could be compromised by both cognitive and auditory declines, it is not surprising that they experience a greater degree of difficulty than younger adults in following and understanding spoken language in complex acoustic environments, but the exact contribution of these factors is still not well specified.

Previous studies have indicated that age-related declines in peripheral processing (e.g., elevations in audiometric thresholds) contribute substantially to age-related declines in word recognition when there are competing sound sources (Humes & Roberts 1990; Jerger et al. 1991; Humes et al. 1994; Frisina & Frisina 1997; Cervera et al. 2009). In contrast, however, there is also some evidence to suggest that older adults can benefit as much as younger adults from the acoustic cues (such as binaural cues to spatial separation) that facilitate source segregation (Li et al. 2004; Humes et al. 2006; Helfer & Freyman 2008; Humes & Coughlin 2009). Nevertheless, to our knowledge, there have only been three studies that have investigated age-related differences in the use of the top-down, knowledge-driven processes that have been shown to produce a release from informational masking in younger adults.

Humes et al. (2006) have shown that, after controlling for audiometric declines, both younger and older adults benefit from prior knowledge of the target's call sign (knowing the call sign before the target and masking sentence are presented), with younger adults appearing to benefit slightly more than older adults in some conditions. Singh et al. (2008), following Kidd et al. (2005), presented three Coordinate Response Measure sentences (Bolia et al. 2000) on a trial (one from the left, one from the center, and one from the right) to both younger and older adults. They found that both younger and older adults were equally affected when the call sign was presented to the participant (before or after presentation of the three sentences) and by a priori knowledge of the probability that the target would be presented from the possible locations. Finally, in a recent study, Helfer and Freyman (2008) showed that prior knowledge of the topic of a sentence masked by a speech masker resulted in a significant reduction in informational masking in both younger and older adults, with the extent of the reduction not differing significantly between the two age groups. Hence, the available evidence suggests that older adults can use prior knowledge about stimulus location, target identity (call sign), and topic as effectively as younger adults. The purpose of this study was to investigate the degree to which older adults might benefit from prior partial knowledge of the content of the target speech.

Priming the Listener by Providing Prior Knowledge of Sentence Content

Helfer and Freyman (2008) showed that prior knowledge of the topic category (e.g., "food") of a meaningful sentence (e.g., "The cherries in the bowl are sweet.") reduced informational masking equally in both younger and older adults. This reduction in informational masking could arise because knowledge about the topic of the sentence aids stream segregation and/or because knowledge about the topic provides contextual support that helps to disambiguate partially masked words. Hence, the relative contribution of these two factors to reductions in informational masking was confounded in their study. Because older adults, under some conditions, have been shown to benefit more than younger adults from sentence context (Pichora-Fuller et al. 1995; Pichora-Fuller 2008; Sheldon et al. 2008a), their age advantage in this regard could have offset an age-related reduction in the ability to use topic knowledge to improve stream segregation.

In this study, we investigated whether equivalent amounts of reduction in informational masking could be achieved in younger and older adults by using three kinds of prior knowledge: partial knowledge of the content of the target speech signal, knowledge of the talker's voice, and partial knowledge of the amplitude envelope of the target signal. Furthermore, we minimized the effect of semantic context by presenting semantically anomalous sentences. We then tested whether partial knowledge of the content of these semantically anomalous sentences (all but the final keyword of the target) would affect younger and older adults differently in an informational masking situation. In this experiment, advanced knowledge of part of the target sentence does not provide contextual support for the missing part (the final keyword of the target). Hence, any improvement in performance as a result of having advanced knowledge of part of the target sentence is unlikely due to the use of sentential contextual support to disambiguate the final

TABLE 1. Average age and Mill Hill vocabulary scores for 74 younger and 76 older adults in experiments 1 to 4 (age and vocabulary scores were unavailable for two of the younger participants)

	Age (yrs)		Vocabulary (score out of 20)	
	Younger	Older	Younger	Older
Experiment 1 (n = 32)	20.6 (1.5)	70.5 (3.1)	13.2 (1.8)	14.9 (2.7)
Experiment 2 (n = 32)	20.5 (1.7)	70.0 (3.2)	13.7 (2.0)	16.1 (2.1)
Pilot experiment (n = 24)	21.3 (2.4)	69.5 (3.1)	14.5 (1.6)	14.6 (2.4)
Experiment 3 (n = 32)	20.7 (2.1)	70.7 (5.7)	13.2 (1.5)	14.6 (1.6)
Experiment 4 (n = 30)	21.7 (2.6)	71.5 (4.5)	14.8 (2.6)	16.1 (2.2)
All (N = 150)	20.9 (2.1)	70.5 (4.0)	13.8 (2.0)	15.3 (2.3)

The numbers in brackets indicate the SD from the mean.

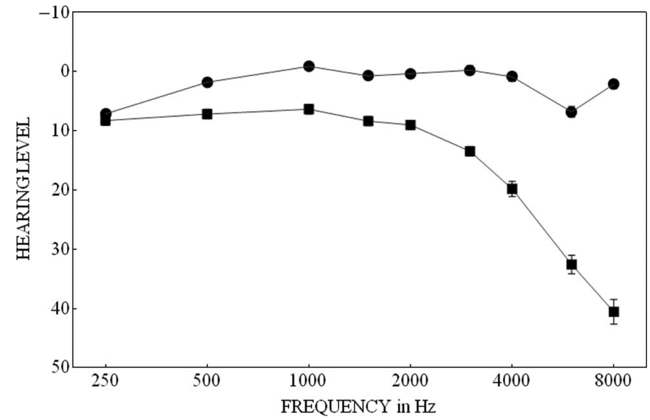
keyword. The specific paradigm we used was based on the materials and procedure used in a prior study by Freyman et al. (2004) in which younger adults were presented with an anomalous target sentence masked by a speech-spectrum noise or a two-talker speech masker in two conditions: when the presentation of the masked target sentence was preceded by the presentation of all but the last word of the same sentence presented in quiet (an auditory prime) and when the masked sentence was not preceded by an auditory prime.

EXPERIMENT 1: PRIMING WITH INITIAL PORTION OF TARGET SENTENCE

In experiment 1, we examined the influence of aging on the extent to which auditory primes can enhance performance when targets and maskers are presented from the same frontal loudspeaker (F-F, for target frontal, masker frontal). Freyman et al. (2004) showed that presenting all but the last word of a target anomalous sentence in quiet, before presenting the full sentence against a background of speech-spectrum noise or two-talker speech, significantly improved perception of the final word for younger adults, presumably by acting as a top-down cue that aids stream segregation. We were interested in determining whether younger and older adults differ in their ability to take advantage of such auditory priming.

Materials and Methods

Participants • Sixteen younger adults (mean age = 20.62 yrs, SD = 1.54 yrs) and 16 older adults (mean age = 70.5 yrs, SD = 3.12 yrs) participated in experiment 1. Younger adults were students recruited from the University of Toronto at Mississauga. Older adults were volunteers from the local community. All participants spoke English as a first language and had clinically normal audiometric thresholds (≤25 dB HL) in both ears from 250 to 3000 Hz. Interaural threshold differences in this frequency range did not exceed 15 dB. Table 1 shows that the Mill Hill (Raven 1965) vocabulary scores for older participants were better than those of younger participants in this and in subsequent experiments. Figure 1 shows that audiometric thresholds were approximately 7 dB higher for older than for younger participants below 3 kHz, but this age-related difference increased with frequency for frequencies above 2 kHz. The criteria for participant inclusion in subsequent experiments were identical to those in experiment 1.*



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Materials and Apparatus • The target sentences were 208 anomalous sentences spoken by a female talker (Helfer 1997). These sentences are semantically anomalous, but they are grammatical and always end with a noun (e.g., "A house should dash to the bowl." or "A frog will arrest the pit."). These sentences were the original recorded stimuli and maskers used by Helfer (1997) and Freyman et al. (1999).

Priming sentences were constructed by removing the last word of each target sentence and replacing it with approximately 700 msecs of white noise whose average root mean square (RMS) amplitude was adjusted to be approximately 10 dB lower than that of the target sentences. Because of concerns raised by Freyman et al. (2004) about the presence of acoustic transition cues when final words were removed from the priming sentences, all sentences were edited using GoldWave sound editing software until one of the authors as well as an independent naïve rater were no better than chance at guessing the first phoneme of the missing word in the priming sentences.

Two maskers were used: a 327-second-long speech-spectrum continuous noise masker recorded from an Interacoustic AC5 audiometer (Interacoustics, Assens, Denmark) and a two-talker anomalous speech masker. The two-talker speech masker consisted of a 315-sec track played in a loop in which two female talkers continuously uttered anomalous sentences that were different than those used for the target sentences. All stimuli were digitized at 20 kHz using a 16-bit Tucker Davis

*A 2 (Age) by 5 (Experiment) analysis of variance (ANOVA) on Mill Hill scores revealed a significant main effect of Age ($F[1,140] = 16.683$, $p < 0.001$) and Experiment ($F[4,140] = 2.852$, $p = 0.026$) but no significant interaction between these two factors. Hence, age differences in vocabulary did not vary across experiments. An Age by Frequency by Experiment ANOVA on audiometric thresholds revealed neither a significant main effect of Experiment nor any two- or three-way interaction of Experiment with Age or Frequency.

Technologies (TDT, Gainesville, FL) System II and custom software. The stimuli were converted to analog using the TDT under the control of an Optiplex GX1 Dell computer. The stimuli were then low-pass filtered at 10 kHz, amplified by a

TABLE 2. Average thresholds in dB SNR for 50% correct identification for the younger and older group in experiments 1 to 4

	Younger			Older		
	No Prime	Prime	Release	No Prime	Prime	Release
Experiment 1						
Speech	−3.5 (2.3)	−6.3 (2.7)	2.8 (3.1)	0.4 (1.3)	−2.3 (1.5)	2.7 (2.1)
Noise	−2.7 (1.2)	−4.3 (0.8)	1.6 (1.3)	−0.3 (1.4)	−2.3 (1.3)	2.0 (1.1)
Experiment 2						
Speech	−3.0 (2.6)	−2.5 (1.7)	−0.5 (2.9)	0.7 (3.0)	0.6 (1.6)	0.1 (2.9)
Noise	−2.6 (1.0)	−2.3 (1.1)	−0.3 (1.5)	−0.9 (1.7)	−1.1 (1.9)	0.2 (1.4)
Experiment 3						
Speech	−1.7 (2.3)	−1.1 (2.9)	−0.6 (2.4)	1.2 (2.0)	1.0 (1.7)	0.2 (1.4)
Noise	−2.1 (1.0)	−2.7 (1.1)	0.6 (1.1)	−0.7 (1.1)	−1.0 (1.2)	0.3 (1.2)
Experiment 4						
Speech	−5.4 (0.1)			−2.6 (2.2)		
Noise	−2.3 (1.2)			−0.2 (1.9)		

Threshold values were derived from individual psychometric functions. Release from masking was computed by subtracting thresholds in the Prime condition from those in the No prime condition. The numbers in brackets indicate the SD from the mean.

to the data are logistic psychometric functions of the following form:

$$y = \frac{1}{1 + e^{-\sigma(x-\mu)}}$$

where y represents the probability of correctly identifying a keyword, x is the SNR in dB, μ is the SNR corresponding to 50%-correct identification, and σ determines the slope of the psychometric function. Psychometric functions were computed by minimizing χ^2 (see Yang et al. 2007 for a description of the fitting procedure). An examination of Figure 2 suggests that the amount of release from masking due to the prime was larger for the speech masker than for the noise masker, but that the release from masking due to the prime was the same for younger and older adults in all conditions. In addition, the slopes of the psychometric functions appear to be steeper for the noise masker than for the speech masker. In general, older adults seem to need a higher SNR than younger adults to achieve equivalent performance.

To confirm whether this pattern of results was found for individual participants, we fitted psychometric functions to the data from each individual. The average values of μ (50%-correct threshold) for participants in each age group are displayed in Table 2, along with release from masking values (average difference between the No Prime and Prime conditions in the SNR required for 50%-correct performance) for each masker. The average values of σ (slope of the psychometric function) for participants in each group are displayed in Table 3. An ANOVA with Age as a between-subjects factor and Prime and Masker as within-subject factors revealed a significant effect of age on thresholds ($F[1,30] = 81.72$, $p < 0.001$). On average, older adults required a 3.1 dB higher SNR to perform at the same level as younger adults. This is not surprising given that the audiograms of the older adults, although in the normal range for frequencies <3 kHz, exhibit evidence of hearing loss for frequencies >3 kHz (see Fig. 1). Because the cut off frequency for the speech material used here was 8 kHz, it is likely that the speech stimuli were less audible to older than to younger adults because of a moderate degree of high-frequency hearing loss, and that this accounts, in part, for the 3.1-dB difference in SNR to perform equivalently to younger adults.

As can be seen in Figure 2, younger adults performed better with the two-talker speech masker than with the speech-spectrum noise masker, whereas older adults performed equivalently under both masking conditions. This trend was confirmed by an ANOVA showing that the main effect of masker on thresholds was not significant, but that there was a significant Masker by Age interaction ($F[1,30] = 7.945$, $p = 0.008$).

The main effect of Prime was also significant ($F[1,30] = 61.20$, $p < 0.001$). As can be seen in Figure 2, average thresholds were lower when a priming sentence was presented compared with when no priming sentences were presented. However, as Figure 2 shows, the improvement due to primes was not equivalent for both maskers, and this is reflected by the significant interaction of Prime by Masker ($F[1,30] = 5.014$, $p = 0.033$). On average, priming resulted in a significantly greater improvement (2.8 dB versus 1.8 dB) when the masker was two-talker speech than when it was speech-spectrum noise. Importantly, the interactions of Prime by Age and Prime by Masker by Age were not significant, suggesting that older adults were equivalent to younger adults in the extent to which they benefited from priming, and that they exhibit the same pattern of improvement as do younger adults.

TABLE 3. Average slopes for individual psychometric functions for the younger and older groups in experiments 1 to 4

	Younger		Older	
	No Prime	Prime	No Prime	Prime
Experiment 1				
Speech	0.41 (0.48)	0.19 (0.06)	0.35 (0.1)	0.27 (0.1)
Noise	0.43 (0.08)	0.40 (0.1)	0.33 (0.1)	0.34 (0.09)
Experiment 2				
Speech	0.29 (0.12)	0.31 (0.09)	0.32 (0.08)	0.36 (0.09)
Noise	0.44 (0.13)	0.37 (0.08)	0.35 (0.07)	0.36 (0.08)
Experiment 3				
Speech	0.34 (0.18)	0.39 (0.57)	0.35 (0.08)	0.37 (0.12)
Noise	0.43 (0.11)	0.42 (0.09)	0.40 (0.06)	0.37 (0.07)
Experiment 4				
Speech	0.23 (0.01)		0.20 (0.06)	
Noise	0.40 (0.02)		0.33 (0.09)	

The numbers in brackets indicate the SD from the mean.

The slopes of the functions were also analyzed. An ANOVA examining estimated values of σ did not reveal a significant main effect of Age, and none of the Age by Prime, Age by Masker, or Age by Prime by Masker interactions was statistically significant. However, there was a significant main effect of Prime ($F[1,30] = 5.156$, $p = 0.031$), as well as a significant main effect of Masker on σ ($F[1,30] = 4.776$, $p = 0.037$), and a significant interaction of Prime by Masker ($F[1,30] = 5.075$, $p = 0.032$). A Student-Newman-Keuls (SNK) test of multiple comparisons revealed that slopes were statistically equivalent for both prime conditions when the masker was noise, but priming reduced the slope when the masker was speech ($p < 0.05$). The slopes for the speech masker when there was no prime did not differ from slopes for the noise masker regardless of whether the target sentence was primed or not.

Discussion

The results from experiment 1 clearly demonstrate that presenting all but the last word of a target anomalous sentence in quiet, before presenting the full target sentence in a competing background, significantly improves the recognition of the target sentence's final word, both when the background consists of continuous speech-shaped noise and a two-talker masker. Consistent with previous findings (Freyman et al. 2004; Yang et al. 2007), the priming advantage with respect to thresholds is significantly greater when the background is two-talker babble than when it is speech-shaped noise. Presumably, as Freyman et al. (2004) argue, the content prime helps the participant focus attention more quickly on the target, thereby facilitating final word recognition in both kinds of background. The greater release from masking observed for the two-talker masker than for the noise masker presumably reflects the greater degree of informational masking in the former than in the latter condition.

The most important finding from experiment 1, however, is that older adults are equivalent to younger adults in the amount of benefit they gain from priming by the portion of the sentence before the target word, suggesting that older adults are as capable as younger adults in using the prime to facilitate parsing the auditory scene and recognizing words.

Furthermore, the results from experiment 1 replicated previous findings (Li et al. 2004; Helfer & Freyman 2008) in that they show the same age-related elevation in thresholds (approximately 3 dB) in the presence of both kinds of maskers. In addition to a general elevation in thresholds, the Age by Masker interaction on 50%-correct thresholds in this experiment indicates that younger adults have better performance with the speech masker than with the noise masker (SNK test, $t[30] = 4.62$, $p < 0.05$), whereas the older adults perform equivalently with both maskers (SNK test, $t[30] = 1.02$, $p > 0.05$).

One interpretation of the finding of an Age by Masker interaction could be that older adults experience more informational masking from the speech maskers. Perhaps because of cognitive declines in selective attention or inhibitory control, they are less able than younger adults to overcome the interference created by the informational content of the speech masker. However, the Age by Masker interaction could also be due to age-related declines in auditory temporal processing (Schneider & Pichora-Fuller 2001). These deficits might prevent older adults from taking advantage of temporal fluctuations in the targets and maskers (George et al. 2006; Lorenzi et al. 2006) and/or it might be more difficult for them to use differences in the fundamental frequency of the voices to segregate streams (Humes et al. 2006; Vongpaisal & Pichora-Fuller 2007; Helfer & Freyman 2008). These alternatives are explored in experiment 4.

EXPERIMENT 2: PRIMING BY VOICE

In experiments 2 and 3, we examine the factors responsible for the priming effect found in experiment 1.

There are at least three potential cues provided by primes that could independently, or in combination, lead to improved source segregation and word recognition. First, by providing listeners with knowledge of the content of the initial portion of the target sentence, the primes could aid stream segregation by engaging top-down processes that allow listeners to identify and track target sentences in noise. Second, hearing part of the target sentence in quiet first may familiarize listeners with the target talker's voice. Familiarity with the target talker's voice might help the listener to follow the target talker's voice when it is encountered in the presence of background sources. Finally, the primes provide information regarding the amplitude fluctuations of target sentences, which could serve word segmentation and guide listening to the unfolding sentence (Sanders et al. 2002; Sanders & Astheimer 2008).

It is worth noting that the priming effect found by Freyman et al. (2004) occurred even when the priming sentences were presented in written form. However, their result does not rule out the possibility that voice familiarity or information regarding the amplitude envelope could act as priming cues. In fact, there is evidence from previous studies to suggest that familiarity with a target talker's voice can be beneficial when listening to speech in noisy backgrounds. Indeed, Brungart et al. (2001) have shown that prior experience with a target speaker's voice can aid the segregation of targets from competing streams in younger adults, and Yang et al. (2007) and Huang et al. (2010) found, for Chinese listeners, that there was a small but significant release from masking when the target sentence presented in noise was preceded by the same person uttering a different anomalous sentence in quiet. Yonners and Sommers (2000) also found that voice familiarity provided an advantage to listeners in identifying words, and they showed that older adults were at least as capable as younger adults in taking advantage of this cue, despite showing poorer recognition of voices.

It is therefore possible that priming with the voice of a talker immediately before presenting the target sentence in noise could make it easier to isolate and extract this voice when it is a target stream among several competitors in a noisy environment. We examined this possibility in experiment 2 and also set out to determine whether there were any age-related differences if voice familiarity did prove to be of benefit.

Materials and Methods

Participants • Another set of 16 younger adults (mean age = 20.86 yrs, SD = 1.56 yrs) and 16 older adults (mean age = 70 yrs, SD = 3.18 yrs) were recruited to participate in experiment 2. All participants met the same criteria as those described for experiment 1.

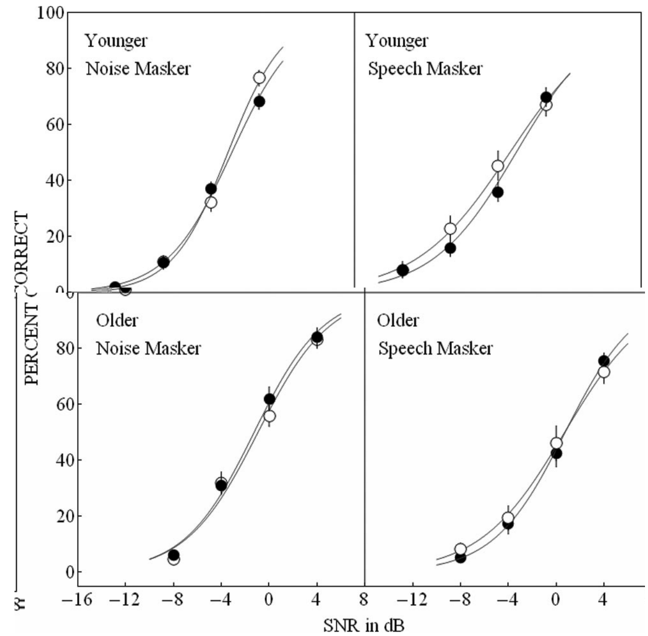
Materials, Apparatus, and Procedure • The 208 anomalous target sentences and the maskers were the same as those in experiment 1. A separate set of 110 anomalous sentences was used as primes. These anomalous sentences were spoken by the target talker so that the voice was the same for all the prime and corresponding target sentences; however, none of the words in the new primes were related to the words in the target sentences. As with experiment 1, the last word of each priming sentence was removed and replaced by a 700-msec white noise whose average RMS was adjusted to be approximately 10 dB lower than the level of the target sentences. The apparatus and procedures were identical to those in experiment 1.

Results

To determine whether or not presenting the stimuli twice had an effect on the performance of the listeners in the two age groups, we again averaged over the SNR conditions and analyzed the results using a 2 (Retest) by 2 (Prime) by 2 (Masker) by 2 (Age) ANOVA with Age as a between-subjects factor. The ANOVA revealed a significant effect of Retest ($F[1,30] = 21.005$, $p < 0.0001$) and a significant Retest by Masker interaction ($F[1,30] = 12.564$, $p = 0.001$). On average, performance improved when the materials were repeated; however, this improvement was greater when the background masker was speech than when it was noise. Therefore, subsequent analyses of data were carried out separately for the speech and noise maskers, collapsing across replications.

Figure 3 plots percentage correct word identification score as a function of SNR for the speech masker (right panels) and for the noise masker (left panels). There is no evidence in Figure 3 to suggest that the presence of a prime has any positive effect on 50%-correct thresholds, for either speech or noise maskers, or for either age group. A 2 (Prime) by 2 (Age) ANOVA of 50%-correct thresholds for words presented with speech maskers confirmed a significant effect of age (50%-correct thresholds for older adults were 3.44 dB higher than those of younger adults, $F[1,30] = 30.373$, $p < 0.001$), but there was no significant main effect of Prime nor a significant interaction of Prime by Age. The corresponding ANOVA conducted on the 50%-correct thresholds when the masker was noise also found a main effect of Age (50%-correct thresholds for older adults were 1.44 dB higher than those for younger adults, $F[1,30] = 9.476$, $p = 0.004$), but there was no main effect due to priming or any significant interaction of Prime and Age ($F[1,30] = 0.050$, $p = 0.825$ and $F[1,30] = 0.802$, $p = 0.378$, respectively). Note that the age-related difference in thresholds for targets presented in the speech masker in experiment 2 was approximately the same as the corresponding age-related difference in thresholds observed in experiment 1 (3.44 dB versus 3.95 dB in experiments 2 and 1, respectively), and that the effect of age on the thresholds for targets presented in the noise masker was also nearly equivalent in the two experiments (1.44 dB versus 2.22 dB for experiments 2 and 1, respectively).

Equivalent ANOVAs were also conducted on the slopes of the psychometric functions for the two types of maskers. There were no significant main effects on slopes due to priming or age or any significant interaction effects between these two factors when targets were presented in speech maskers or noise maskers.



F . 3. A [illegible] 2. [illegible] E [illegible]

Discussion

We examined the influence of voice priming on the identification of words in anomalous sentences presented in two-talker speech or speech-spectrum noise but found no statistically significant benefits for either younger or older adults. Because these sentences were the same length and format as those used in experiment 1, and because the primes in both experiments were spoken by the same talker, it is reasonable to conclude that the priming advantage provided in experiment 1 was not caused by familiarity with the speaker's voice. These results are consistent with those of Newman and Evers (2007), who did not find voice familiarity to be beneficial to speech perception in noisy environments. However, our results are inconsistent with those obtained by Yang et al. (2007) and Huang et al. (2010) who did find a benefit from voice priming when young adults were tested using identical procedures with similar Chinese utterances. A likely explanation for the apparent discrepancy could be differences between English and Chinese; for example, as a tonal language, voice cues might be of greater significance for the identification of phonemes in Chinese than they are for a nontonal language such as English.

EXPERIMENT 3: PRIMING BY ENVELOPE CUES

In addition to information about the linguistic content of the sentences, and information about the vocal characteristics of the target talker, the priming sentences in experiment 1 provide

TABLE 4. Boundary frequencies (Hz) for the 2- to 8-band noise-vocoded nonsense sentences

2 band	300	1528	6000						
4 band	300	722	1528	6000					
6 band	300	494	814	1528	2210	3642	6000		
8 band	300	477	722	1061	1528	2174	3066	4298	6000

information about the amplitude envelope of the target sentences. It is thus possible that the benefit provided by the auditory primes in experiment 1 of this study, and in the experiment carried out by Freyman et al. (2004), is in part due to the envelope information provided by the primes. If so, priming listeners with the envelope information of target sentences before their presentation in background speech or noise should result in a significant improvement in performance. Experiment 3 was carried out to examine this hypothesis. To preserve as much of the envelope information as possible, while eliminating the semantic content of the vocoded speech signal, the priming sentences from experiment 1 were noise vocoded. A pilot experiment was carried out in which the target sentences were noise vocoded to determine how the number of bands used in vocoding would affect word identification, with the aim being to find the highest number of bands that could be used while dramatically reducing intelligibility.

Materials and Methods

Noise vocoding (Shannon et al. 1995) is a process in which the amplitude envelope of a speech signal is extracted for a certain frequency band, and the envelope is then used to modulate noise within the same frequency band (Shannon et al. 1995; Eisenberg et al. 2000). This procedure preserves amplitude envelope cues while eliminating fine structure cues. The intelligibility of noise-vocoded speech increases as the number of bands is increased, and near-perfect word recognition can be achieved by normal-hearing younger adults with as few as 4 bands when a closed set of words in simple sentences is used (Shannon et al. 1995).

Pilot Experiment • In a pilot experiment, we determined the number of bands that would result in 15% or less word identification accuracy for our stimuli. The target sentences used in experiments 1 and 2 were vocoded using 2, 4, 6, and 8 bands in the same fashion as described by Sheldon et al. (2008b) and using procedures outlined by Eisenberg et al. (2000). To extract the envelopes of the bands, the magnitude of the Hilbert transform was computed and passed through a low-pass filter with a cutoff frequency of 160 Hz. The bandwidths used are given in Table 4.

Twelve younger (mean age = 21.25 yrs, SD = 2.38 yrs) and 12 older adults (mean age = 69.55 yrs, SD = 3.15 yrs) who had not participated in experiments 1 or 2 took part in the pilot experiment. All participants spoke English as a first language and had clinically normal hearing with no significant interaural asymmetry up to 3000 Hz.

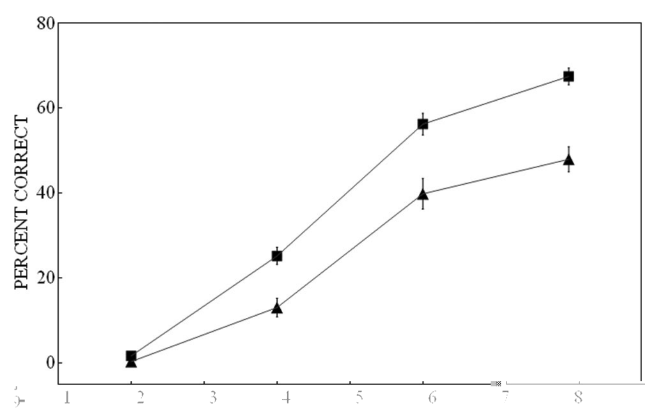
All materials and equipment used to determine the number of bands to be employed in experiment 3 were identical to those used in experiments 1 and 2, and the stimuli were presented in the same test room and using the same equipment as in experiments 1 and 2. Four target lists were presented for each band condition (2, 4, 6, or 8 bands) at 60 dBA, with no competing stimuli in the background. Participants were asked to repeat each sentence immediately after its presentation, and responses were scored for all three keywords for a total of 156 keywords presented at each band. Participants were tested only once.

The percentage of words identified correctly by the younger and older adults at each band condition is plotted in Figure 4. Figure 4 shows that older adults required more bands to achieve a level of performance equivalent to that achieved by younger adults, consistent with the results of Sheldon et al. (2008b). For younger adults, linear interpolation between the 2- and 4-band conditions indicated that they should be able to identify approximately 13% of the words if 3 bands were used. Figure 4 also shows that older adults can correctly identify 13% of the words when 4-band vocoding is used. Hence, in experiment 3, we used 3-band vocoding for younger adults and 4-band vocoding for older adults because these conditions met our criteria for maximizing envelope information while minimizing the informational content of the priming sentences.

Main Experiment

Participants • Another set of 16 younger (mean age = 20.67 yrs, SD = 2.09 yrs) and 16 older adults (mean age = 70.70 yrs, SD = 5.65 yrs) who had no previous exposure to the stimuli participated in the main experiment. All participants met the same criteria as the participants in the earlier experiments.

Materials, Apparatus, and Procedure • The equipment and testing situation used in experiment 3 were identical to those used in experiments 1 and 2. In experiment 3, the priming sentences used in experiment 1 were noise vocoded using 3 bands for the younger adults and 4 bands for the older adults. Again, 700 msecs of white noise, whose average RMS was adjusted to be approximately 10 dB lower than the target sentences, was added to the end of each priming sentence. The



F . 4. A [illegible]

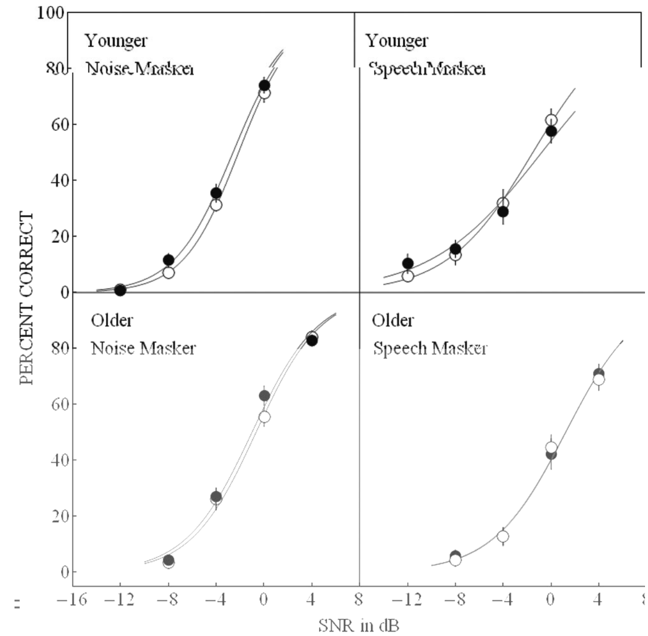
speech-spectrum continuous noise masker and two-talker speech masker used in this experiment were the same as those used in experiments 1 and 2. The test procedure was identical to that used in experiments 1 and 2.

Results

To see whether performance improved when the stimuli were repeated, the number of words identified correctly was averaged over SNR conditions and analyzed using a 2 (Retest) by 2 (Prime) by 2 (Masker) ANOVA with Age as a between-subjects factor. There was a significant main effect of Retest on performance ($F[1,30] = 23.023$, $p < 0.001$); on average, the difference in the percentage of correctly recalled words between the second and first test was 2.7 percentage points. There was, however, a significant interaction of Age and Retest ($F[1,30] = 4.485$, $p = 0.043$). Although younger adults improved by an average 3.88% from the first to the second presentation of the stimuli, older adults only showed a 1.51% improvement in performance; consequently, it is possible that the age effects in this experiment could be somewhat inflated insofar as the performance of the two groups seems to have diverged because of learning. Because no other interactions involving Retest were statistically significant, data from the first and second presentations were averaged and used to obtain individual psychometric functions.

The accuracy with which the final word was identified is plotted as a function of SNR in Figure 5, with separate panels for each background masker. Although younger adults performed better than older adults in all conditions, the presence of a vocoded prime did not seem to produce any significant improvement in performance for either age group (see Table 2). This description was confirmed by an ANOVA with Age as a between-subjects factor and Prime as a within-subjects factor. There was a significant main effect of age ($F[1,30] = 19.942$, $p < 0.001$). On average, older adults required a 2-dB higher SNR to perform at the same level as younger adults. This age-related difference did not depend on the type of masker, because the Age by Masker interaction was not statistically significant ($F[1,30] = 2.206$, $p = 0.148$). The analysis did not reveal a significant main effect of Prime ($F[1,30] = 0.249$, $p = 0.622$) nor a significant interaction of Prime by Age ($F[1,30] = 0.236$, $p = 0.630$).

There was a significant main effect of Masker ($F[1,30] = 18.905$, $p < 0.001$), but unlike the findings in the earlier experiments, there was not a significant Age by Masker interaction. Participants, regardless of age, performed better when the masker was speech-spectrum noise than when it was two-talker speech (mean difference between speech masker and noise masker = 1.45 dB), consistent with notion that speech maskers produce more informational masking. However, the absence of an Age by Masker interaction in the present experiment contradicts the findings in the No Prime conditions of experiments 1 and 2, where younger adults performed approximately equivalently for the two maskers. To see whether there were significant differences across the three experiments, we conducted an Experiment by Age by Masker ANOVA on the threshold values for the No Prime conditions that were common to the three experiments. This ANOVA found significant effects of Age ($F[1,90] = 78.827$, $p < 0.001$), Masker ($F[1,90] = 5.445$, $p = 0.022$), and an Age by Masker interaction ($F[1,90] = 12.748$, $p = 0.001$) but no



F . 5. A

significant effect due to experiment or any interactions between experiment and the other factors. In separate ANOVAs performed on the thresholds for the younger and older participants, no significant effects of experiment or masker or masker by experiment were found for the younger adults; for the older adults, there was no significant effect of experiment and no significant experiment by masker interaction, but there was a significant effect of masker. Hence, older adults, but not the younger adults, find it more difficult to identify the target when the masker is speech than when it is noise. These results suggest that the failure to find an interaction between age and masker in experiment 3 likely reflects the small effect size for this interaction and a lack of power to detect this effect in this particular experiment.

An analysis of the slopes of the psychometric function using a 2 (Age) by 2 (Prime) by 2 (Masker) ANOVA did not reveal significant main effects of age, prime, masker, or any significant two-, or three-way interactions between these factors.

Discussion

In the pilot experiment, we noise vocoded the target sentences used in experiments 1 and 2, using 2, 4, 6, and 8 bands, and tested younger and older adults' ability to repeat these sentences in quiet. Based on the results of the pilot experiment, it was determined that noise vocoding sentences using 3 bands for the younger adults and 4 bands for the older adults would not convey too much informational content. The priming sentences used in experiment 1 were noise vocoded using 3 bands for the younger adults and 4 bands for the older adults. Experiment 1 was then repeated using the noise-vocoded priming sentences. Priming participants with the envelope information provided by the noise-vocoded prime did not improve the identification of the final keyword when the target sentences were subsequently presented with a speech-spectrum noise or a two-talker speech masker. It seems unlikely then that the release from masking provided in experiment 1 (priming with the initial portion of the target sentence) is attributable to envelope information conveyed by the priming sentences.

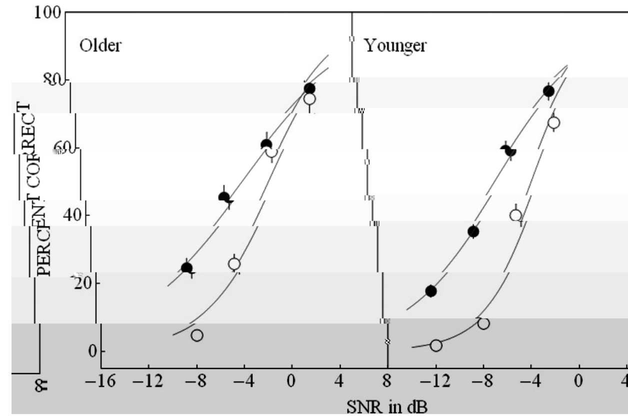
EXPERIMENT 4: SPEECH-SPECTRUM NOISE MASKER VERSUS NOISE-VOCODED SPEECH MASKER

An analysis of the combined results obtained in the No Prime conditions in experiments 1 to 3 indicated that there was a significant interaction between Age and Masker, such that older adults performed significantly better with the speech-spectrum noise masker than with the two-talker speech masker in the background, whereas younger adults performed equivalently with the two masker conditions. This Age by Masker interaction could potentially be caused by older adults' poorer ability to take advantage of fluctuations in the envelope of the speech masker (Duquesnoy 1983; Pichora-Fuller & Souza 2003; George et al. 2006). To test this hypothesis using the same anomalous target sentences as had been used in the previous experiments, in experiment 4, the two-talker speech masker used in experiments 1, 2, and 3 was noise vocoded using 3 bands, and the vocoded masker was compared with the speech-spectrum noise masker used in the previous experiments. The rationale for using 3 bands was to preserve some of the temporal variation in the speech masker while still ensuring that most individual words in the masker are not recognized. The pilot experiment conducted to guide the selection of an amount of vocoding to use in experiment 3 indicated that only 13% of the individual words in single sentences vocoded using 3 bands were recognized. Hence, we assumed that when the two-talker speech masker was vocoded, the interference from the linguistic content of the masker would be even less.

Materials and Methods

Participants • A group of 16 younger adults (mean age = 21.7 yrs, SD = 2.64 yrs) and a group of 16 older adults (mean age = 71.5 yrs, SD = 4.47 yrs) who had not participated in any of the previous experiments were recruited for experiment 4. All participants met the same inclusion criteria as had been met by the participants in the earlier experiments.

Materials, Apparatus, and Procedure • The two-talker speech masker from experiments 1, 2, and 3 was noise vocoded with 3 bands using the method described in experiment 3. All other materials and equipment were identical to those used in experiments 1, 2, and 3, except that no priming was involved in this experiment. Testing was conducted in the same test room using the same procedure as in the previous experiments. Because we did not use any primes in this experiment, the number of different target sentences was augmented by also using the sentences previously used in priming conditions.



F . 6. A [illegible]

Participants were scored on the final keyword of target sentences and were tested only once (there was no repetition of the items).

Results

The average percentage of correctly identified final keywords is plotted as a function of Age and Masker in Figure 6. As can be seen in this figure, younger adults outperformed older adults under both masking conditions. The figure also shows an improvement in performance relative to the continuous noise masker, when target sentences are heard in the presence of the noise-vocoded masker, with the degree of improvement being about the same for the younger and older adults.

The thresholds for 50%-correct word recognition obtained from individual psychometric functions under each Age by Masker condition were analyzed with a 2 (Age) by 2 (Masker) ANOVA. As expected, the analysis revealed a significant main effect of Age ($F[1,30] = 23.727$, $p < 0.001$). On average, older adults required a 2.3 dB higher SNR to perform at the same level as younger adults. The main effect of Masker was also significant ($F[1,30] = 94.348$, $p < 0.001$). Thresholds were on average 2.72 dB lower when the target was masked by vocoded speech than when it was masked by speech-spectrum noise. More importantly, the interaction of Age by Masker was not statistically significant ($F[1,30] = 0.690$, $p = 0.413$), indicating that the older participants were as able as the younger participants to benefit from the fluctuations in the noise-vocoded speech masker.

The slopes were also analyzed. An ANOVA conducted on the slopes of the psychometric functions revealed a significant main effect of Age ($F[1,30] = 6.415$, $p = 0.017$) and Masker ($F[1,30] = 78.638$, $p < 0.001$). However, the interaction of Age by Masker was not statistically significant ($F[1,30] = 0.690$, $p = 0.413$). On average, younger adults had significantly steeper slopes than did older adults (mean difference = 0.046), and both younger and older adults had steeper slopes in the continuous noise background than in the noise-vocoded background. Thus, overall, performance increased more rapidly as a function of SNR for younger compared with older adults and also more rapidly for both age groups when there was a continuous noise masker in the background than when there was a noise-vocoded masker in the background.

Discussion

In experiments 1, 2, and 3, older adults had more difficulty identifying the final word of anomalous sentences when there was a two-talker speech masker compared with when there was a continuous noise masker, whereas the performance of younger adults did not differ under the two masking conditions. One possible explanation for this result is that older adults may be less able than younger adults to take advantage of the troughs in the amplitude envelope of the speech masker to gain a "glimpse" of the target signal (Cooke 2006). The results of experiment 4, however, indicated that older adults benefited as much as younger adults from amplitude fluctuations in the vocoded speech masker relative to their performance against a continuous noise masker. Nevertheless, it should be noted that 3-band vocoding does not provide the same degree of amplitude fluctuation that characterizes the intact speech masker. It may be that younger and older adults experience equivalent release from masking when 3-band vocoding is used, but that younger adults might have obtained a greater degree of release than older adults if more bands had been used in vocoding the masker. However, it was not possible to use more bands of vocoding because including more bands would ultimately result in restoring the semantic content, such that there would be an inevitable confound among the number of bands of vocoding, the extent of informational masking, and the availability of dips in the masker.

The larger age-related difference in performance when the masker is two-talker speech than when it is either a continuous speech-spectrum noise or noise-vocoded speech would also be expected if older adults were more susceptible to informational masking of speech by speech. To test this hypothesis more directly, we compared the thresholds of younger and older adults when listening in a background of two-talker speech (experiments 1 to 3) versus listening in a background of noise-vocoded two-talker speech (experiment 4). Because noise vocoding removes most of the semantic content of the speech masker, it should provide close to the maximum release from informational masking of speech by speech. Hence, if we compared the performance of younger and older adults when tested with a two-talker speech masker and a noise-vocoded speech masker, we would expect a greater release from informational masking in older adults than in younger adults if older adults were indeed more susceptible to informational masking. The pattern of results was consistent with this expectation, i.e., the average release from masking for the older adults was indeed higher than that for the younger adults (3.4 dB versus 2.6 dB, respectively). However, an Age (younger adults versus older adults) by Masker (intact speech masker versus noise-vocoded speech masker) ANOVA on the 50%-correct thresholds did not reveal a significant Age by Masker interaction ($F[1,124] = 0.700$, $p = 0.404$), indicating that the improvement in performance observed in the noise-vocoded speech masker relative to the intact speech masker was equivalent for younger and older adults.

Hence, there is no evidence that older adults experience more informational masking than younger adults when the test materials are anomalous sentences. A similar conclusion concerning the lack of age-related differences was also reached by Helfer and Freyman (2008).

GENERAL DISCUSSION

The purpose of this study was to investigate whether older adults are as able as younger adults to benefit from various types of priming when listening to target speech signals in various masking conditions. In experiment 1, listeners were presented with all but the last word of a target anomalous sentence immediately before the presentation of the full target sentence with masking by a two-talker speech masker or a speech-spectrum noise masker. There was a greater release from masking when the masker was two talkers speaking anomalous sentences than when it was speech-spectrum noise, thereby demonstrating that this type of priming produces a release from informational masking that is equivalent for both younger and older adults.

In experiment 2, where we investigated priming by voice, the same maskers were used as experiment 1, but the prime was all but the last word of an anomalous sentence that was unrelated to the target sentence. Priming by voice of the target speaker did not result in any improvements in performance for either age group when compared with the conditions in which no priming sentences were presented.

Similarly, results from experiment 3 rule out that the release from masking due to priming observed in experiment 1 was due to the envelope information provided by the primes.

Finally, in experiment 4, we noise vocoded the two-talker speech masker using 3 bands to minimize the informational content of the masker while retaining envelope information and compared performance with this vocoded masker to that observed with the standard speech-spectrum noise masker. The performance of both younger and older adults was better when the masker was the noise-vocoded speech masker than when it was the continuous speech-spectrum noise masker, suggesting that younger and older adults benefit equally from amplitude fluctuations in noise-vocoded speech when the semantic content of the masker is greatly reduced.

Taken together, our results indicate that older adults are as able as younger adults to use top-down knowledge-driven processing to segregate competing auditory streams and enhance word recognition in noisy situations. It is important to note that this does not mean that the ability of older adults to recognize words in these situations is equivalent to that of younger adults. In this experiment, older adults required an average 3 dB higher SNR in all conditions to match the word recognition levels of younger adults. Hence, in identical noisy listening situations, younger adults will outperform older adults, presumably because of age-related declines in auditory processing even when the audiometric thresholds are considered to be clinically normal throughout most of the speech range. However, despite these age-related declines in hearing, the top-down mechanisms used in auditory scene analysis seem to be preserved in aging, thereby providing equivalent amounts of release from masking in both age groups. This conclusion is consistent with other studies that have found top-down auditory mechanisms that provide release from masking to be preserved with aging (Pichora-Fuller et al. 1995; Murphy et al. 2006; Sheldon et al. 2008b; Singh et al. 2008).

Although naturally spoken speech was used in the experiments, there are important differences between our stimuli and those typically encountered in everyday communication. First, our stimuli were anomalous sentences. Even though there is evidence that such sentences elicit semantic and syntactic processes that could influence lexical access (Wingfield et al. 1985), it would seem that any age-related differences that existed in these processes had little influence on word recognition in this experiment. However, it is unlikely that our tasks engaged the full range of semantic, syntactic, and lexical mechanisms that are deployed during more everyday listening. Second, the sentences used here were relatively short, and participants were required to repeat them immediately after they were presented. Therefore, demands on memory were likely minimal, possibly obscuring age-related differences in performance associated with deficits in memory. An additional issue is that the two-talker speech masker also consisted of anomalous sentences. As such, it was not as likely to be as disruptive to performance as meaningful speech might have been. Indeed, Tun et al. (2002) have shown that older adults suffer more when meaningful background speech is presented than when distracters are nonmeaningful (e.g., made up of random strings of letters or a foreign language). It is possible that using meaningful target and masking sentences would have resulted in age-related differences in informational masking.

Finally, as noted by Freyman et al. (2004), although the primes could trigger top-down processing that is beneficial to stream segregation, it is unlikely that they are frequently encountered in natural situations. One rarely hears a partial preview of a sentence in quiet first during conversation in a noisy background. However, priming has some similarity to asking a talker to repeat parts of an already spoken sentence (Schneider et al. 2007), and prior knowledge of the topic of a conversation could prime listeners for sentences that are about to be encountered (Helfer & Freyman 2008). In this case, knowledge of the topic of conversation might aid processing by constraining the set of possible words that are likely to be encountered as a target sentence unfolds. Thus, by knowing what to expect, one only needs evidence from the auditory input to confirm preexisting expectations about what is likely to be encountered next in a sentence or conversation (Bregman 1990).

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