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Aging, Spacial Cues, and Single-Versus Dual-Task Performance in Competing Speech Perception

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Aging, spatial cues, and single- versus dual-task performance in competing speech perception[a)]

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Older individuals often report difficulty coping in situations with multiple conversations in which they at times need to "tune out" the background speech and at other times seek to monitor competing messages. The present study was designed to simulate this type of interaction by examining the cost of requiring listeners to perform a secondary task in conjunction with understanding a target talker in the presence of competing speech. The ability of younger and older adults to understand a target utterance was measured with and without requiring the listener to also determine how many masking voices were presented time-reversed. Also of interest was how spatial separation affected the ability to perform these two tasks. Older adults demonstrated slightly reduced overall speech recognition and obtained less spatial release from masking, as compared to younger listeners. For both younger and older listeners, spatial separation increased the costs associated with performing both tasks together. The meaningfulness of the masker had a greater detrimental effect on speech understanding for older participants than for younger participants. However, the results suggest that the problems experienced by older adults in complex listening situations are not necessarily due to a deficit in the ability to switch and/or divide attention among talkers.
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I. INTRODUCTION

Successful auditory communication often requires both selective and divided attention. At some points in time, listeners selectively attend to one stream of speech while ignoring one or more competing sounds. At other times, individuals might monitor more than one conversation and then narrow the focus of their attention to an individual message. Previous research suggests that considerable costs are associated with dividing and switching attention. For example, performance is poorer when individuals are required to divide attention between auditory sources as compared to when they must simply selectively attend to one message (e.g., Best *et al.*, 2006; Humes *et al.*, 2006; Ihlefeld and Shinn-Cunningham, 2008), although the size of the cost seems to depend on the precise nature of the tasks (e.g., Moore and Massaro, 1973; Gallun *et al.*, 2007). Processing of simultaneous speech streams may be particularly taxing because a single limited-capacity system is called upon for both sound source segregation and speech recognition (Navon and Gopher, 1979; Gallun *et al.*, 2007).

Difficulty understanding speech in complex listening environments is a common complaint among older adults. Since communicating under such conditions requires both bottom-up and top-down processing, problems in either (or both) of these areas would be expected to contribute to these difficulties. Older adults often demonstrate a reduction in the ability to benefit from silent gaps in a modulated speech masker (e.g., Takahashi and Bacon, 1992; Summers and Leek, 1998; Dubno *et al.*, 2002, 2003; George *et al.*, 2006) and problems segregating a target signal from competition (e.g., Alain *et al.*, 1996; Rose and Moore, 1997; Mackersie *et al.*, 2001; Snyder and Alain, 2007). There also are well-documented changes in cognitive processing with advanced age that likely contribute to problems understanding speech in a multi-talker environment. These changes include a reduction in the amount of attentional capacity and/or problems with effectively allocating attentional resources (e.g., Hoyer and Plude, 1982; Madden, 1990). Further, peripheral hearing loss associated with aging may have an "upstream" effect on cognitive processing (e.g., Murphy *et al.*, 2006). The present study was designed to address how requiring younger and older listeners to devote attention to a secondary task affects speech perception in a complex listening situation.

There is a growing body of literature documenting that older adults have difficulty understanding speech in the presence of competing speech (Carhart and Tillman, 1970; Duquesnoy, 1983; Tun and Wingfield, 1999; Tun *et al.*, 2002; Li *et al.*, 2004; Humes *et al.*, 2006; Singh *et al.*, 2008; Helfer and Freyman, 2008; Agus *et al.*, 2009; Rossi-Katz and Arehart, 2009). One question that has not yet been answered definitively is *why* older adults experience these problems. Some data suggest that differences between older and younger listeners on tasks of competing speech perception can be explained by factors related to peripheral hearing loss such as inaudibility of portions of the target speech (e.g., Li *et al.*, 2004) or a reduced ability to benefit from masker fluctuations (e.g., Takahashi and Bacon, 1992; Vongpaisal and Pichora-Fuller, 2007). Other work supports

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the idea that both auditory and cognitive factors play a part in problems experienced by older listeners. For example, older adults are at a greater disadvantage than younger listeners when the masker is changed from non-meaningful speech to meaningful speech (e.g., Tun *et al.*, 2002; Larsby *et al.*, 2005; Rossi-Katz and Arehart, 2009) or from random word strings to semantically correct sentences (Tun *et al.*, 2002), findings which cannot be explained by audibility. Moreover, while high-frequency hearing loss often can account for a large proportion of the variability in speech understanding in noise, it typically is not related to speech understanding in competing speech situations where the target and masker are difficult to segregate (e.g., Humes *et al.*, 2006; Helfer and Freyman, 2008; Helfer and Vargo, 2009).

As mentioned above, in real-world communication situations listeners often are attending to one person's speech while monitoring background conversations. There is evidence that young, normally hearing listeners can monitor auditory information from one channel while attending to another channel (e.g., Cherry, 1953; Treisman, 1960) even to the extent that the unattended signal can be processed for lexical information (Rivenez *et al.*, 2006). However, results of other work support the idea that only one auditory object can be attended to at a time (e.g., Vogel and Luck, 2002; Shinn-Cunningham, 2008) and that at least in the visual domain, multiple locations can be attended to only for a very brief period of time, after which attention can only be focused on one location (Dubois *et al.*, 2009). It is likely that in many complex listening situations individuals are not necessarily dividing their attention between spatial locations (i.e., actually listening to both channels simultaneously), but are rapidly switching their attention between channels.

These complex environments are often very challenging for older individuals. Although part of the difficulty they experience is undoubtedly due to the peripheral auditory changes described above, it is likely that changes in attentional processes also contribute to this decrement in speech understanding. Studies of divided attention typically find that requiring individuals to perform simultaneous tasks exerts a greater cost on older adults than on younger adults (e.g., Wright, 1981; Craik and McDowd, 1987; Tun *et al.*, 2009), although this is not a universal finding (e.g., Nyberg *et al.*, 1997). Aging effects on dual-task performance vary as a function of the specific tasks, being larger when the two tasks depend on a single process or on similar processes (e.g., Lindenberger *et al.*, 2000). Results of studies of task switching have found mixed results. In general, aging effects in task-switching experiments are not found when the participant is pre-cued to the switch in advance but sometimes occur when this is not the case (e.g., Verhaeghen and Cerella, 2002; Kray, 2006).

Of particular interest in the present study is how spatial separation affects dual-task performance by younger and older adults. There is strong research evidence that spatial separation makes selective attention easier, as it can decrease both energetic and informational masking and enhance segregation of the sound sources (e.g. Freyman *et al.*, 1999, 2001; Brungart *et al.*, 2001; Ihlefeld and Shinn-Cunningham, 2008). Much less is known about how spatial separation affects performance in divided listening tasks, although there is a good deal of relevant information from the visual processing literature. These data support the idea that there is some type of limit on spatial attention (such as a "spotlight") that leads to reduced performance when attending to more than one spatial location (e.g., Treisman and Gelade, 1980; Eriksen and St. James, 1986). In other words, when the focus of attention must be broadened beyond the size of the purported spotlight, performance declines in relation to trials where attention is focused within the limits of the spotlight. There have been only a few investigations designed to test whether such a feature operates in the auditory domain. Studies that demonstrate better performance for competing speech perception at expected (vs unexpected) spatial locations (e.g., Kidd *et al.*, 2005; Singh *et al.*, 2008; Kitterick *et al.*, 2010) or faster response times to target tones on trials with accurate (vs inaccurate) spatial cues (Mondor and Zatorre, 1995) could be taken as evidence of some type of auditory spatial spotlight. Data from Arnott and Alain (2002), who found a reduction in the amplitude of the mismatch negativity response to sounds presented at unattended locations, also could be taken as support for a spatially limited auditory attention window. There also is direct evidence of some type of spatial spotlight in audition. Best *et al.* (2006) found a small negative effect of spatial separation on the perception of two equal-level speech messages, partially supporting the spotlight idea. Recently, Allen *et al.* (2009) demonstrated that speech recognition in the presence of speech maskers decreases as distance from an attended location increases. However, work by Ihlefeld and Shinn-Cunningham (2008) suggests that spatial separation may actually enhance divided listening. Specifically, spatial separation improved the ability to repeat the softer of two messages but did not substantially affect the understanding of the louder signal.

Older adults, even those with hearing loss, appear to retain the ability to benefit from spatial separation of a target speech signal from a speech masker in selective attention tasks (Li *et al.*, 2004; Singh *et al.*, 2008), although the amount of benefit obtained by older adults may be reduced by either hearing loss or by aging itself (Duquesnoy, 1983; Arbogast *et al.*, 2005; Humes *et al.*, 2006; Murphy *et al.*, 2006; Marrone *et al.*, 2008). Little is known about how aging influences spatial attention in divided listening. Studies of visual processing, however, have found age-related narrowing in spatial attention (Hartley and McKenzie, 1991; Madden and Gottlob, 1997; Atchley and Hoffman, 2004).

The purpose of the present work was to determine how aging and spatial separation affect speech perception in a competing speech paradigm during both single- and dual-task performance. Of particular interest was comparing the costs associated with requiring older vs younger adults to switch/divide attention. Most studies of dual-task costs in speech perception use divided-attention tasks that require listeners to respond to both of two simultaneously presented messages. The goal of the present study was to simulate a listening situation in which individuals must monitor a second conversation while attending to a primary message but not necessarily understand both speech streams. The paradigm used here is similar to that of Gatehouse and Akeroyd (2008) in which listeners had to identify a word and its

location while also monitoring another auditory signal and indicating when it was about a specific topic. In the present study, the primary task required participants to repeat back a target sentence in the presence of two competing sentences. The secondary task was to determine whether neither, one, or both of the masking sentences was played backward. It has long been known that some listeners can identify a switch from forward to time-reversed speech in an unattended channel (e.g., Cherry, 1953; Wood and Cowan, 1995). To the best of our knowledge, no one has examined how readily listeners can discriminate between forward and backward messages within a mixture of voices. The task of determining if a voice is presented backward appeared to us to be a viable means of directing the listener's attention to one lower-level (e.g., non-lexical) aspect of a competing message.[1] Using this secondary task had the added benefit of allowing us to examine the effect of the meaningfulness of a speech masker on speech recognition performance of younger and older listeners, since there were trials in which the masker was understandable as well as those in which the masker was not understandable.

II. METHODS

A. Stimuli and participants

The stimuli for this experiment were sentences from the TVM Corpus (Helfer and Freyman, 2009). These sentences each have the form "____ discussed the ____ and the ____ today" where the first blank is one of three cue names (Theo, Victor, or Michael) and the second and third blanks are one- or two-syllable nouns used for scoring. The sentences are presented in an open-set format; that is, listeners are not given possible choices of key words. These sentences were recorded from three male talkers (see Helfer and Freyman, 2009 for additional details about these stimuli). On each trial, participants heard three sentences, each spoken by a different talker and beginning with a different cue name.

Two groups of adults were run. The first consisted of ten college students (20–38 yr, mean age 23 yr) with normal hearing verified by audiometric screening at 25 dB hearing level (HL) for pure tones between 250 and 8000 Hz. The second group was ten older listeners (60–69 yr, mean age 63 yr) who met the following inclusion criteria: no more than a mild sensorineural hearing loss up to and including 4 kHz; bilaterally symmetric (within 10 dB) pure-tone thresholds; bilaterally normal tympanograms; and no history of neurologic or otologic disorder. A composite audiogram for the older participants is shown in Fig. 1. All participants completed the experiment in one 1.5–2.5 h test session. Older listeners were paid a nominal amount ($10) for participating, while younger listeners earned extra credit points.

B. Procedures

The experiment was run in a double-walled Industrial Acoustics Company (IAC) sound chamber. Two loudspeakers (Realistic Minimus 7) were used to present the stimuli, one directly in front of the listener and the other at 60° to the right of the participant. The loudspeakers were placed at a distance of

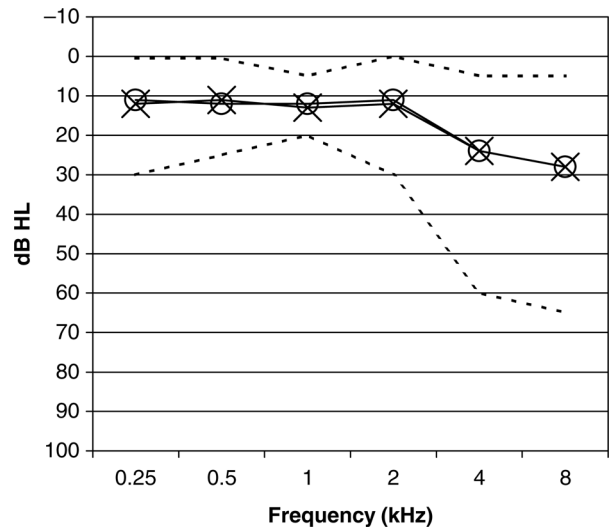

FIG. 1. Composite audiogram for the older participants. Dashed lines represent the minimum and maximum thresholds for all older listeners.

1.3 m from the participant's head at a height of 1.2 m from the floor. Stimuli were played out of a computer's sound card, attenuated (TDT PA4), amplified (TDT HBUF5), and then power amplified (TOA P75D) before being sent to the loudspeaker(s).

For half of all trials the three sentences were presented from one loudspeaker located directly in front of the listener (hereafter referred to as F-F, for front-front); on the other half of the trials (termed F-RF, for front-right front), one sentence was presented from the front and the other two sentences were presented from both the front and right loudspeakers with a 4-ms lead to the right. Due to the precedence effect, this produced the perception of spatial separation between the utterances presented from the front vs those presented from both loudspeakers while producing minimum release from energetic masking (e.g., Freyman *et al.*, 1999). We have used this method in several previous investigations of speech understanding by both younger (e.g., Freyman *et al.*, 1999, 2001) and older (Helfer and Freyman, 2008) listeners. It should be noted that there is evidence suggesting that somewhat different results are obtained when comparing speech understanding under real spatial separation to that measured using a precedence-effect paradigm (Singh *et al.*, 2008). We chose to use a precedence-effect paradigm in order to minimize the potentially confounding effects of aging and/or hearing loss on the amount of energetic masking between spatial conditions.

Three different types of trials were completed, comprising single- and dual-task performance. In trial type 1, three sentences were presented simultaneously, each beginning with a different cue name and spoken by a different talker. Participants were told to ignore the sentence beginning with a designated cue name and to indicate (via a key press) whether neither, one, or both of the other messages were presented backward. Half of all the trials used the F-F spatial mode, where all three sentences were presented from the front loudspeaker. The other trials used the F-RF mode, in which the to-be-ignored sentence was presented from the front loudspeaker while the two other sentences were presented from both the front and side loudspeaker in order to

produce spatial separation. On half of all trials, both of the to-be-attended sentences were presented forward (normally); one-quarter of trials had one to-be-attended sentence presented backward and one presented forward; and the remaining quarter of trials had both to-be-attended sentences presented backward. Listeners responded by pressing a key on a computer keyboard indicating the number of messages perceived as being played backward (0, 1, or 2).

Trial type 2 was recognition of key words within the TVM sentences. The conditions were identical to those used in trial type 1 but the participant's task was different. On each trial participants heard three different TVM sentences, each beginning with a different cue name, and were instructed (via text on a computer screen) to repeat back the sentence beginning with one of the cue names (hereafter referred to as the target sentence). The target sentence was always presented from the front loudspeaker; for half of all trials the two other sentences (hereafter referred to as the masking sentences) were also presented from the front loudspeaker, and the remaining trials used the F-RF presentation mode. As for trial type 1, the other two sentences were presented forward for half of all trials with the remaining half of trials divided equally between one sentence presented forward/one sentence presented backward and both sentences presented backward. Listeners responded verbally and their responses were scored online by an experimenter.

Trial type 3 measured dual-task performance. The same stimuli and conditions that were used for trial types 1 and 2 were employed here, but participants had to complete both tasks. That is, they were asked to repeat back the target sentence and then indicate (via a key press) whether neither, one, or both of the maskers was presented backward. Participants were asked to divide their attention equally between the two tasks.

Trial type was blocked within the experiment, with 72 trials presented per trial type. The results of piloting showed a strong effect of order of presentation; specifically, participants who completed trial type 3 last had substantially poorer performance on the speech recognition task as compared to those who received trial type 2 last. Therefore, half of the participants in each group received trial type 2 before trial type 3, and the other half had this order reversed. All listeners completed trial type 1 first. Within each block, spatial configuration (F-F or F-RF) and masker direction were randomized from trial to trial. Each listener was given a brief practice session (six trials) with each trial type before data collection began. To-be-ignored sentences (for trial type 1) and target sentences (for trial types 2 and 3) were presented at 65 dBA and the combination of the two other sentences was presented at 63 dBA. No adjustment in target or masker level was made for the F-RF condition even though the masking complex was presented from an additional loudspeaker (and, as a result, was 3 dB greater than in the F-F condition).

III. RESULTS

A. Single- vs dual-task performance

Percent-correct data (shown in Fig. 2) from the two types of tasks (forward/backward discrimination and speech understanding) were transformed into rationalized arcsin units (RAU) (Studebaker, 1985) prior to data analysis. Table I shows the mean data and standard errors in RAU. Overall, performance was poorer for the older listeners than for the younger listeners. The data were analyzed using two separate repeated-measures analysis of variance (ANOVA) (one for the speech perception task and another for the direction task) with spatial condition and single- vs dual-task performance as within-subjects variables and group as a between-subjects variable. For the speech perception task, there were significant main effects for both spatial configuration [F (1, 18) = 19.37, $p < 0.001$] and single- vs dual-task performance [F (1, 18) = 5.34, $p = 0.03$], as well as a significant interaction between spatial configuration × single/dual task [F (1, 18) = 5.44, $p = 0.032$]. Main and interaction effects in involving participant group were non-significant. For the direction task, significant main effects were found for spatial configuration [F (1, 18) = 18.57, $p < 0.001$], single- vs dual-task performance [F (1, 18) = 24.61, $p < 0.001$], and participant group [F (1, 18) = 4.92, $p = 0.040$]. None of the interactions reached statistical significance.

Of primary interest was comparing costs associated with dual-task performance between older and younger listeners and between spatial configurations. The simple difference between single- and dual-task scores was calculated for each participant and the mean values are shown in Fig. 3. In this figure, higher bars indicate larger dual-task costs. Perhaps unexpectedly, the mean costs associated with performing two tasks were larger in our younger (vs older) participants. However, this difference failed to meet statistical significance, likely because of the large individual variability for this factor within both groups. ANOVAs on the cost data (computed from the RAU scores) were completed for the speech recognition task as well as for the direction task. The results for the speech recognition task showed a significant main effect for spatial configuration [F (1, 18) = 5.44, $p = 0.032$], with larger costs noted in the spatially separated F-RF condition than for the spatially coincident F-F condition. Neither the main effect of participant group nor the interaction of spatial configuration × group was significant. An analysis of the direction task costs showed no significant main or interaction effects.

One notable trend in the data was that requiring participants to divide their attention between two tasks greatly reduced the benefits associated with spatial separation. This can be seen in Fig. 4, which displays the spatial release from masking (SRM) averaged across listeners for the two types of tasks. In this figure, higher bars correspond to larger amounts of spatial benefit. It is obvious that the positive effect of separating target from masker is noticeably larger for single-task performance than for dual-task performance for both types of tasks. An ANOVA on the SRM data (with type of task and number of tasks as within-subjects variables and group as a between-subjects variable) confirmed this observation, demonstrating a significant main effect of single- vs dual-task performance [F (1,18) = 8.49, $p = 0.009$]. Main and interaction effects involving participant group were not statistically significant, although inspection of Fig. 4 suggests that older participants had a greater SRM for the

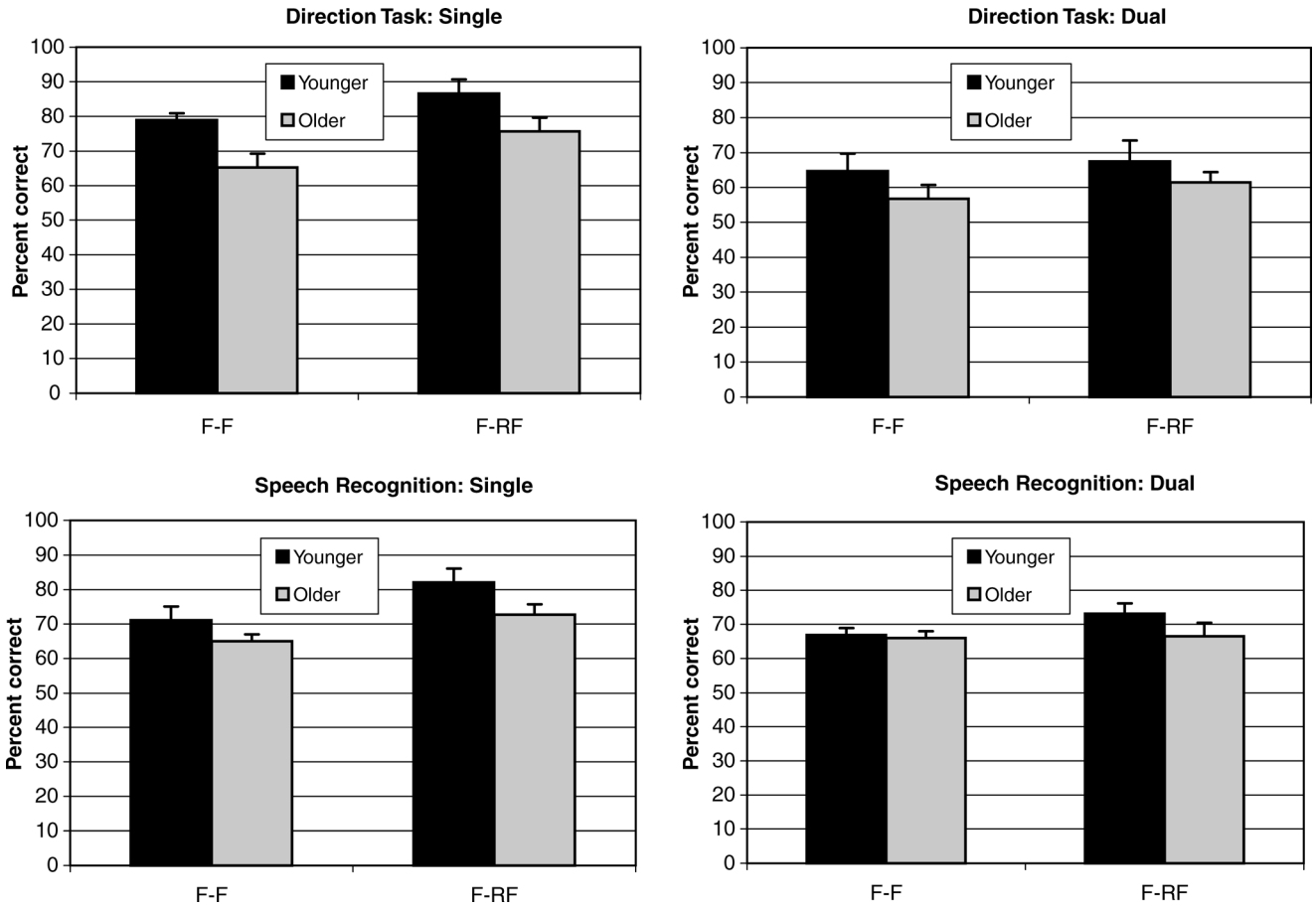

FIG. 2. Performance on the direction task (top panels) and speech recognition task (bottom panels) for single-task (left panels) and dual-task (right panels) conditions. Error bars represent the standard error.

direction task but had less SRM for the speech recognition task (as compared to the younger adults) for both single- and dual-task performance. Particularly striking is the fact that, for older listeners, there was virtually no benefit of separating target from masker for the speech recognition task in dual-task conditions.

Also of interest was determining if there were any connections between listener age and/or degree of hearing loss and task variables. Pearson r correlations were computed on the older participants' data to examine the influence of age and high-frequency pure-tone thresholds (the average of better-ear thresholds for 4 and 8 kHz). High-frequency thresholds were not significantly associated with any variables. Significant associations were found between age and performance on the direction task in the F-F configuration. The correlation coefficient was positive for the single-task condition ($r = 0.79$, $p < 0.01$) and negative for dual-task ($r = -0.67$, $p = 0.03$). This led to a very strong correlation between age and the cost associated with dividing attention on the direction task in the F-F condition ($r = 0.93$, $p < 0.01$), which is depicted in a scatter plot in Fig. 5. This correlation was still highly

TABLE I. Average mean data and standard errors (in parentheses) for each participant group in RAU.

Listening condition	Younger group	Older group
Direction task:		
F-F single-task	78.95 (1.98)	65.20 (4.24)
F-RF single-task	86.69 (3.67)	75.70 (4.48)
F-F dual-task	64.67 (4.87)	56.70 (3.59)
F-RF dual-task	67.47 (5.84)	61.40 (2.70)
Speech recognition task:		
F-F single-task	71.04 (4.31)	65.00 (2.08)
F-RF single-task	82.09 (4.09)	72.70 (2.79)
F-F dual-task	66.91 (2.45)	66.00 (1.70)
F-RF dual-task	73.15 (3.35)	66.50 (3.56)

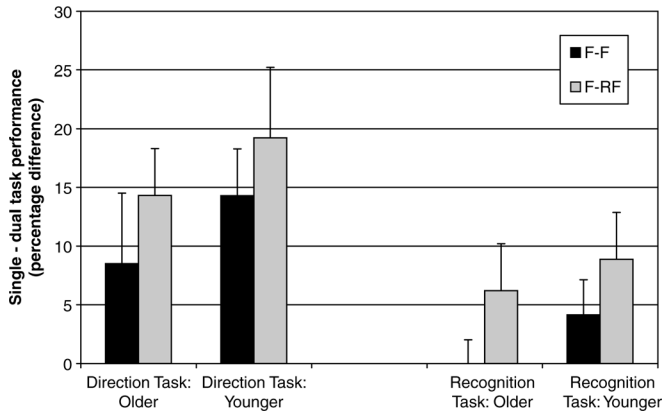

FIG. 3. Costs associated with dual-task performance (single-task performance minus dual-task performance for each of the two tasks) averaged across participants. Error bars represent the standard error of the mean cost across listeners.

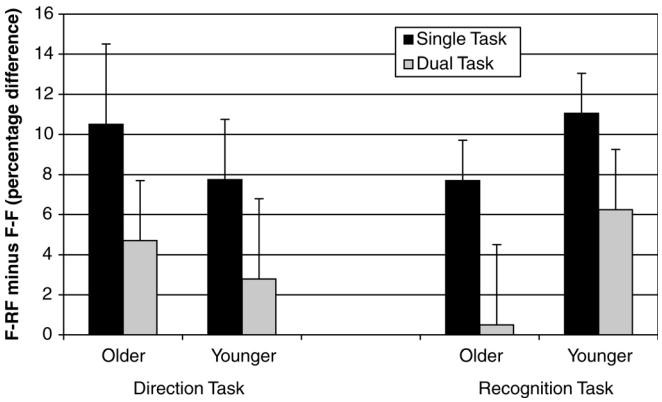

FIG. 4. Spatial release from masking (the difference in percent-correct performance for the spatially separated F-RF trials vs that measured for the spatially coincident F-F trials) averaged across participants. Error bars represent the standard error of the mean benefit across listeners.

significant ($r = 0.90$, $p < 0.01$) when the outlier (the 69-yr-old participant's data point) was eliminated. It should be noted that this participant had, by far, the best performance of all older listeners for single-task trials on the direction task and the poorest performance of all listeners for dual-task trials.

B. Effect of type of masker

A number of previous studies (including one from our laboratory) have found data supporting the idea that the understandability of a masker has a larger negative effect for older than for younger listeners (e.g., Tun *et al.*, 2002; Helfer and Freyman, 2009; Rossi-Katz and Arehart, 2009). The data collected in the present experiment allowed us to examine this variable by comparing percent-correct scores on trials with the masking voices presented forward to those obtained when the maskers were presented backward. The difference in target speech recognition performance when both maskers were presented backward vs when the two maskers were presented forward (scores in the presence of two backward maskers minus scores in the presence of two forward maskers) is shown in Fig. 6. Higher bars in this

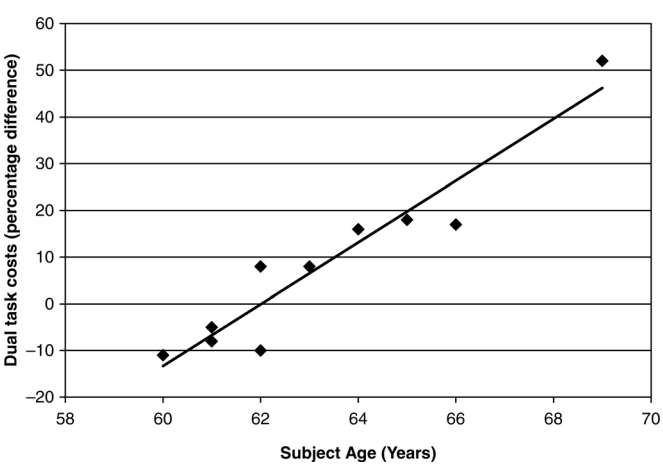

FIG. 5. Scatter plot of the relation between participant age (among the ten older participants) and dual-task costs for the direction task in the spatially coincident configuration. The r value for this correlation is 0.93.

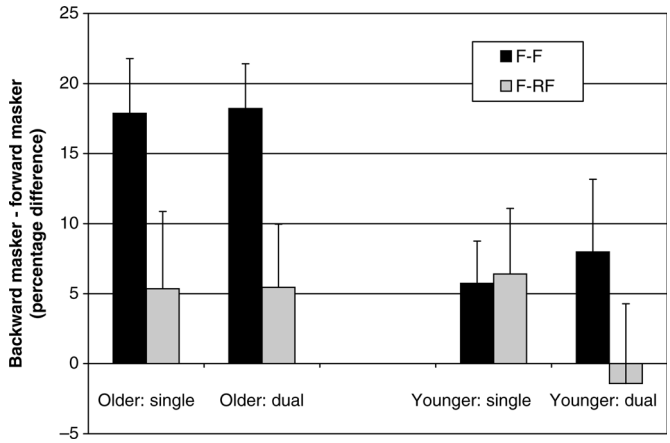

FIG. 6. The effect of intelligibility of the speech masker, as measured by the difference in performance with a two-talker masker presented normally vs a two-talker time-reversed masker (performance in the presence of the time-reversed maskers minus performance in the presence of the forwards maskers).

figure indicate that there was a greater decrement in performance for forward-presented vs backward-presented maskers. It is clear that older adults were at a substantially greater disadvantage than younger listeners when the masker was meaningful (i.e., presented forward), especially in the spatially coincident F-F condition. An ANOVA on these difference scores (calculated from the data after RAU transformation) confirmed a significant main effect of participant group [F (1,18) = 8.32, $p = 0.01$] as well as a significant main effect for spatial configuration [F (1,18) = 4.45, $p = 0.049$]. None of the interactions were significant. This confirms previous studies (e.g., Tun *et al.*, 2002; Larsby *et al.*, 2005) demonstrating that the semantic make-up of a masker has a greater effect on performance for older than for younger listeners. Since this result cannot be explained by peripheral hearing loss, it supports the contention that age-related changes in higher-level processing contribute to older adults' susceptibility to masking from competing speech.

IV. DISCUSSION

The results of the present study documented that there are substantial costs involved when listeners are required to perform two different operations on the same stimulus complex. One notable finding in the present study was that the dual-task costs were greater for spatially separated listening conditions than for spatially coincident conditions. In other words, the addition of a requirement to perform a task at a remote location led to greater decline in performance than when listeners only needed to listen at one location. This result is consistent with some type of spatial spotlight that limits performance outside a certain spatial range (e.g., Best *et al.*, 2006). When listeners must switch the focus of attention or stretch it beyond the limits of the spotlight, performance is negatively affected because additional resources are needed to process multiple or very broad spotlights (e.g., McMains and Somers, 2005).

In contrast to the current results, at least one previous study has found little or no detrimental effect of spatial separation on divided listening (Ihlefeld and Shinn-Cunningham, 2008). Comparisons between the present study and that work should be made with caution, however, because of differences in the nature of the tasks (repeating back two simultaneous sentences vs performing both a speech recognition task and a discrimination task) and the stimuli (closed-set degraded sentences vs open-set natural speech). It is likely that spatial separation advantages in the present study were smaller in dual-task conditions because listeners needed to divert their attention to the masker's perceived location in order to complete the secondary task. This pattern of results is consistent with spatial separation providing benefit in identifying and attending to the target but increasing the costs associated with performing more than one task.

Dual-task costs were greater for the direction task than for the speech recognition task, for both spatially coincident and spatially separated listening. One explanation for this finding lies in the fact that participants were asked to report the target sentence *before* they indicated how many of the masking voices were perceived as being presented backward. Hence, memory was likely to play a larger role in secondary task performance, since participants had to hold their response to this task in memory while repeating back the target sentence. This explanation is supported by the strong correlation found between age and dual-task costs for the direction task among our older listeners, in concordance with evidence that older adults have more difficulty than younger listeners in maintaining multiple tasks in memory (e.g., Kramer and Madden, 2008). However, the reader is advised to interpret this surprisingly strong correlation with caution, as there was no significant difference in dual-task costs between older and younger listeners, and the age range of the older participants in this study was quite limited. An alternative explanation for the greater dual-task costs for the direction task could be that the novelty of this task led to larger performance decrements. This explanation is supported by a body of work suggesting that overlearned tasks (such as understanding speech) show smaller age-related decline than those with which individuals have had less experience (e.g., Salthouse, 1985).

The present study showed only modest differences in speech recognition ability between younger and older listeners for both single- and dual-task conditions. It should be noted that the older participants in this experiment were relatively young (mean age 63 yr) and these individuals had normal or close-to-normal hearing sensitivity. Greater group differences likely would have been obtained if the performance of even older listeners and/or those with hearing loss was measured (e.g., Tun and Wingfield, 1995). The small amount of threshold elevation in our participants did not appear to influence performance, as speech recognition scores were not correlated with high-frequency hearing loss.

It is perhaps unexpected that older adults demonstrated a smaller cost of performing two simultaneous tasks, and speech recognition differences between the older and younger listeners were greater for single-task conditions than for dual-task trials. Age differences are typically noted in divided attention tasks that require listeners to repeat back simultaneous sentences (e.g., Humes *et al.*, 2006) or perform simultaneous speech recognition and visual tracking tasks (e.g., Tun *et al.*, 2009). However, the task used in the present study only required the monitoring of a second channel and not sustained attention; listeners could simply sample the masking complex some time during the trial to determine whether backward speech was present. Therefore, a more relevant comparison is to task-switching studies. Costs associated with task switching can be differentiated between global costs (sometime referred to as "mixing costs"), which appear to measure task selection and the ability to keep multiple tasks in working memory, and local costs (also called "switching costs"), which are believed to indicate the ability to activate one task and de-activate the other. Previous research has demonstrated that aging brings about larger global task-switching costs but has little effect on local task switching (e.g., Verhaeghen and Cerella, 2002) and that when older adults are prepared for the need to switch, minimal or no age differences are noted (e.g., Kray, 2006). Although the comparison between the task used in the present study and traditional task-switching paradigms is not perfect (the method used in the present study was not typical of those used in task-switching research, where the task switch happens between, not within, trials), the fact that we found no significant age differences in the present study (in which listeners knew they would need to change attention during dual-task trials) may indicate that participants were indeed switching the focus of their attention rather than truly dividing attention. Of course, this does not explain why the younger participants experienced greater costs during dual-task performance, which could be related to differences between groups in effort, motivation, and/or the amount of resources devoted to each task. It also should be noted that previous studies of divided attention costs have found that older adults may recruit additional cortical regions during both tasks in order to perform similarly to younger adults, suggesting that older and younger adults use different strategies to successfully resolve dual-task situations (Fernandes *et al.*, 2006).

Older adults demonstrated less SRM than younger listeners for the speech recognition task. In fact, as a group the older listeners obtained almost no benefit from spatial separation for speech recognition in dual-task trials. In our precedence-effect paradigm, these differences in SRM cannot be easily explained by peripheral factors. The results of the present study agree with previous work that shows that older adults do benefit from spatial separation between a masker and target, but less so than do younger listeners (Duquesnoy, 1983; Arbogast *et al.*, 2005; Humes *et al.*, 2006; Murphy *et al.*, 2006; Marrone *et al.*, 2008). Moreover, having to perform two tasks seems to have a greater detrimental effect on SRM for older than for younger listeners. Past work suggests that it takes time for listeners to fully engage attention at a spatial location (Mondor and Zatorre, 1995). It is possible that, compared to younger listeners, older participants took longer to switch attention between spatial locations, leading to less time left to attend to the target during F-RF trials. When interpreting SRM differences between older and younger participants, the fact that spatial separation was achieved using a precedence-effect paradigm should be considered. Previous research suggests that speech

presented with precedence-induced spatial separation may be more difficult to understand than speech presented with real spatial separation (Singh *et al.*, 2008). However, that study found that this difference was equivalent for older and younger adults (Singh *et al.*, 2008).

The understandability of the masker had a much larger effect for older than for younger listeners, replicating results of previous studies (e.g., Larsby *et al.*, 2005; Tun *et al.*, 2002; Rossi-Katz and Arehart, 2009). It is known that speech maskers can cause both energetic masking (i.e., peripheral swamping of neurons by the masker necessary for perceiving the target) and informational masking (higher-level interference caused by uncertainty or confusion). In the present study, the performance difference between conditions with forwards vs time-reversed maskers for single-task trials was approximately the same for our older and younger listeners in spatially separated conditions (5−6 percentage points) but was much greater for our older participants in the spatially coincident situation (18 percentage points). When maskers and target are presented at equal levels, it is likely that using a time-reversed masker reduces informational masking, at least in part by making the target easier to segregate from the masker. In the present study, the fact that target sentences were presented at a greater intensity than the masking sentences likely reduced the amount of informational masking (e.g., Arbogast *et al.*, 2005; Freyman *et al.*, 2007) and it is probable that segregation of the target speech from the masking speech was not a limiting factor in participants' performance. Previous studies have found no evidence of increased informational masking in older adults (e.g., Li *et al.*, 2004; Helfer and Freyman, 2008; Agus *et al.*, 2009). The fact that older adults were at a greater relative disadvantage than younger listeners when having to ignore an understandable masker is not easily explained by an increase in either energetic masking or in confusion/uncertainty (i.e., informational masking). We believe that it is likely due to cognitive interference from having to process an intelligible masker.

In summary, older listeners (mean age 63 yr) with no more than a mild high-frequency sensorineural hearing loss demonstrated slightly decreased overall performance on a task of competing speech perception, in relation to young, normal-hearing listeners. However, there was no evidence of an age-related increase in costs associated with dual-task performance. For both listener groups, dual-task costs for speech understanding were greater when signals were spatially separated vs when they were spatially coincident, supporting the existence of some type of spatial spotlight. The older participants in the present study benefited substantially less than the younger participants from spatial separation of the target from the masker and were more negatively affected by the meaningfulness of the masker.

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[1]A pilot experiment used a task which was perhaps a more accurate simulation of real-life communication in which a listener is monitoring a background conversation for what a particular person is saying. In that study, the secondary task was to determine whether two masking utterances were spoken by the same or by different talkers. This proved to be a very difficult task, with even young, normal-hearing listeners performing just above chance level. Hence, we chose to use the direction task instead since both older and younger listeners were able to perform this secondary measure with reasonable accuracy.

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