Age and Measurement Time-of-Day Effects on Speech Recognition in Noise

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Objectives: The purpose of this study was to determine the effect of measurement time of day on speech recognition in noise and the extent to which time-of-day effects differ with age. Older adults tend to have more difficulty understanding speech in noise than younger adults, even when hearing is normal. Two possible contributors to this age difference in speech recognition may be measurement time of day and inhibition. Most younger adults are "evening-type," showing peak circadian arousal in the evening, whereas most older adults are "morning-type," with circadian arousal peaking in the morning. Tasks that require inhibition of irrelevant information have been shown to be affected by measurement time of day, with maximum performance attained at one's peak time of day. The authors hypothesized that a change in inhibition will be associated with measurement time of day and therefore affect speech recognition in noise, with better performance in the morning for older adults and in the evening for younger adults.

Design: Fifteen younger evening-type adults (20–28 years) and 15 older morning-type adults with normal hearing (66–78 years) listened to the Hearing in Noise Test (HINT) and the Quick Speech in Noise (QuickSIN) test in the morning and evening (peak and off-peak times). Time of day preference was assessed using the Morningness–Eveningness Questionnaire. Sentences and noise were presented binaurally through insert earphones. During morning and evening sessions, participants solved word-association problems within the visual-distraction task (VDT), which was used as an estimate of inhibition. After each session, participants rated perceived mental demand of the tasks using a revised version of the NASA Task Load Index.

Results: Younger adults performed significantly better on the speech-in-noise tasks and rated themselves as requiring significantly less mental demand when tested at their peak (evening) than off-peak (morning) time of day. In contrast, time-of-day effects were not observed for the older adults on the speech recognition or rating tasks. Although older adults required significantly more advantageous signal-to-noise ratios than younger adults for equivalent speech-recognition performance, a significantly larger younger versus older age difference in speech recognition was observed in the evening than in the morning. Older adults performed significantly poorer than younger adults on the VDT, but performance was not affected by measurement time of day. VDT performance for misleading distracter items was significantly correlated with HINT and QuickSIN test performance at the peak measurement time of day.

Conclusions: Although all participants had normal hearing, speech recognition in noise was significantly poorer for older than younger adults, with larger age-related differences in the evening (an off-peak time for older adults) than in the morning. The significant effect of measurement time of day suggests that this factor may impact the clinical assessment of speech recognition in noise for all individuals. It appears that inhibition, as estimated by a visual distraction task for misleading visual items, is a cognitive mechanism that is related to speech-recognition performance in noise, at least at a listener's peak time of day.

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INTRODUCTION

It is well established that older adults tend to have more difficulty understanding speech in the presence of background noise than do younger adults, even when hearing sensitivity is within normal limits (Dubno et al. 1984; Pichora-Fuller et al. 1995; Stuart & Phillips 1996). One factor that may contribute to this apparent age difference is time of day of testing. One of the many changes humans undergo throughout the life span is a change in preference for time of day. Research has demonstrated that, for a variety of cognitive tasks, performance typically peaks at a specific point in the day that corresponds to a peak in the individual's circadian arousal level and that younger and older adults tend to have different arousal patterns and preferences in work and other schedules (Kerkof 1985; Yoon et al. 1999; Schmidt et al. 2007). For example, many young adults demonstrate a preference for "eveningness" or the tendency to have difficulty waking up early and a preference for staying up late, whereas most older adults are characterized by "morningness" or the tendency to prefer rising early in the morning and have difficulty staying up late. Morning-type adults often report feeling their best in the morning and tend to prefer to engage in activities such as going to work or exercising in the morning, when possible; in contrast, evening-type adults typically report feeling sharpest later in the day and tend to prefer to engage in daily activities in the evening. It is possible that older adults' poorer speech-recognition performance in noise, compared with that of younger listeners, is exacerbated by testing at off-peak times of the day.

Many studies investigating the effects of time of day have used the Morningness–Eveningness Questionnaire (MEQ) developed by Horne and Ostberg (1976) to show this significant skew toward morningness among older adults and eveningness among younger adults (e.g., May et al. 1993; Intons-Peterson et al. 1998; May & Hasher 1998; May 1999; May et al. 2005; Monk & Kupfer 2007). In addition, this scale has demonstrated a strong correlation with physiological measures such as sleep–wake cycles (Webb 1982) and self-report measures of alertness (West et al. 2002). Ezzatian et al. (2010) used the MEQ in their study investigating the effects of time of day on age-related differences in auditory performance; for auditory detection tasks such as within-channel gap detection, they found no significant differences associated with time of day among younger or older adults.

Inhibitory control, or the ability to suppress irrelevant information from consciousness, is thought to play a major role in several cognitive processes and appears to be strongly affected by time of day preference. Most studies showing time-of-day effects on inhibition investigated inhibitory control primarily in the visual modality. Although older adults show relatively inefficient inhibitory control compared with younger adults (Zacks et al. 1996; Hasher et al. 2002), both younger and older adults are less susceptible to distractions (Rowe et al. 2006) and may

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more efficiently suppress information that is no longer relevant (May & Hasher 1998; May 1999; Hasher et al. 2002) at the time of day corresponding to their peak level of circadian arousal. For example, younger adults have demonstrated increased interference on the Stroop color-naming task (Stroop 1935) at off-peak compared with peak times of day (May & Hasher 1998). May and Hasher (1998) demonstrated that individuals also show less control over inappropriate motor responses when tested using a stop-signal paradigm at off-peak compared with peak times of day; the stop-signal paradigm in this study required participants to judge whether a word was a member of a given category by pressing one of two keys on a keyboard, but after the task was well-practiced, some trials were preceded by a tonal signal that indicated the participants should withhold their response. Both younger and older participants were less likely to avoid making unwanted responses for the trials preceded by the tonal signal when tested at off-peak times of day. May (1999) compared younger and older participants on word problem performance in the presence and absence of visual distracters and showed a reduced ability across age groups to suppress distracting visual information at off-peak test times compared with peak times, with younger participants demonstrating poorer performance earlier in the day and older participants showing poorer performance later in the day.

Inhibition is believed to support working memory, or the ability to hold and manipulate information in active use (Wingfield et al. 2005), by allowing only relevant information into memory and by suppressing irrelevant or unnecessary information from memory (West et al. 2002); therefore, it would be expected that working memory is influenced by the time of day as well. Whereas older adults have consistently demonstrated poorer word recall in working-memory tasks than younger adults, both younger and older adults show better recall memory for words at their peak time of day, with younger adults recalling more words in the evening than in the morning and older adults recalling more words in the morning than in the evening (Hasher et al. 2002; May et al. 2005). Similarly, for recognition memory of sentences, younger adults demonstrated better recognition in the evening than in the morning, whereas older adults demonstrated better recognition in the morning than in the evening (May et al. 1993).

In addition to its role in visual processing and working memory, inhibition is thought to play a role in other cognitive processes, such as selective attention and speech comprehension (May & Hasher 1998). Thus, a change in inhibitory control (and therefore, the ability to ignore distracting stimuli) associated with the time of day of testing may result in a change in speech-recognition ability in noise. Moreover, this change in inhibitory control with time of day may act differentially to affect the performance of younger and older listeners. In noisy environments, the listener must ignore the distracting sounds to focus on relevant speech information and, thus, may have to rely, in part, on inhibitory control to accomplish this task (Tun et al. 2002). Because inhibition has been shown to be less efficient at off-peak times of day, speech-recognition ability in noise may also be poorer at off-peak times of day. Moreover, because one consequence of aging is a reduction in inhibitory control, testing speech recognition in noise at off-peak times of the day may result in exaggerated performance deficits for older listeners.

To date, only one other study is known to have investigated the effects of measurement time of day on inhibitory control in hearing. Ezzatian et al. (2010) investigated age and time-of-day effects on performance on three auditory detection tasks: (1) within-channel gap detection; (2) tonal intensity differentiation; and (3) memory for spoken discourse in multi-talker babble. The authors confirmed age-related differences in performance on all three tasks, with younger adults showing better performance than older adults. The only significant time-of-day effect on performance was among the older adult participants on the gap-detection task. Participants were tested at 9:00 A.M., 11:30 A.M., and 3:30 P.M. on the same day, and older adults (all "morning-type" individuals, based on the MEQ) showed significantly better gap-detection thresholds during the first test session compared with the second and third sessions. However, the authors argue that this interaction between age and time of day is not likely a result of changes in circadian rhythms, as there was a trend for younger adults (all "evening-type" individuals) to also perform better in earlier sessions. Although gap detection is considered a measure of sensory performance and, therefore, may not be expected to be affected by changes in inhibitory control associated with time of day, memory for spoken discourse has been shown to be affected by time of day (May et al. 1993) and is likely to involve some degree of inhibitory control when the discourse is presented in multi-talker babble. No significant effects of time of day were found among participants of either age group for memory for spoken discourse in multi-talker babble.

Because reductions in inhibitory control at off-peak measurement times of day have been shown to negatively affect performance on a variety of cognitive tasks, it is possible that individuals may perceive these tasks as requiring greater effort as inhibitory control decreases. Previous research has shown that subjective measures of workload often correspond to task performance; for example, Harris et al. (2010) demonstrated that as gap-detection task complexity increased, older adults showed both poorer performance and higher subjective ratings of workload than did younger adults. However, in some cases, perceived effort or task demand may be a more sensitive indicator of difficulty than task performance itself. To date, little research has investigated a possible relationship between inhibition and perceived effort, but Sarampalis et al. (2009) demonstrated that a change in cognitive demand required for a task can occur without a change in performance on the task itself. Through dual-task experiments designed to measure the cognitive demands of understanding speech in background noise while responding to complex visual stimuli, Sarampalis et al. (2009) showed that participants responded more quickly to the visual stimuli when listening to speech in noise with a noise-reduction algorithm in their hearing aids than without the algorithm. Based on the improved performance on the secondary task of responding to visual stimuli, it was inferred that fewer cognitive demands were used in the primary task of listening to speech with the noise-reduction algorithm. Their study demonstrated that measures of cognitive demand were more sensitive than measures of speech recognition to the effects of noise-reduction algorithms in hearing aids. Therefore, perceptions of effort and task demand should be considered when investigating changes in inhibition, as they could prove to be more sensitive indicators of inhibitory control than performance itself.

The present study was designed to determine if age and measurement time of day interact to have an effect on speech-recognition ability in noise. The Quick Speech in Noise

(QuickSIN) test (Killion et al. 2004) and the Hearing in Noise Test (HINT; Nilsson et al. 1994) were selected as measures of speech recognition in noise for this study, because they often are used clinically to assess patients' ability to understand speech in the presence of noise; therefore, it may be of clinical relevance to determine the extent to which age and time of day may interact to affect performance on either of these tests. The QuickSIN test, in particular, has been shown to be more sensitive to the speech-recognition deficits that accompany hearing loss than other speech-in-noise tests (Wilson et al. 2007); thus, it was hypothesized that this test may also be more sensitive to age or time-of-day effects. Given that the HINT has been used as a measure of "functional hearing" abilities and predicted occupational performance (Giguere et al. 2008), age and measurement time-of-day effects would be important to quantify. In addition, because each test uses a different type of auditory distraction (speech-spectrum noise for the HINT and four-talker babble for the QuickSIN), it was expected that one test may result in greater time-of-day effects than the other. Previous studies have shown greater speech-recognition difficulty among older listeners in a background of multiple talkers than in a background of steady-state noise (Souza & Turner 1994; Lustig & Hasher 2001). Thus, it was anticipated that the QuickSIN might show greater time-of-day effects, because more inhibitory control may be required to ignore the background speech babble of this test compared with the speech-spectrum noise of the HINT.

A visual-distraction task (VDT) derived from a study by May (1999) on cognitive inhibition was selected for this study as an independent estimate of inhibitory control. There were two reasons for selecting the VDT: (1) May (1999) showed that this task was sensitive to measurement time-of-day effects and (2) because the VDT requires inhibition of semantic content (e.g., leading and misleading distracter words), it was hypothesized that this task may be related to performance on the QuickSIN, which requires inhibition of the semantic content of multi-talker babble. Thus, it was expected that all listeners would exhibit greater inhibition of misleading visual distracters at their peak time-of-day, and that greater inhibition would be related to lower QuickSIN scores.

Given the implications provided by previous research on cognitive processes such as inhibition control, we developed the following hypotheses:

1. All participants, regardless of age, would have better speech recognition in noise performance when tested at their peak time of day (i.e., young adults would perform better in the evening, and older adults would perform better in the morning).
2. Older adults would demonstrate poorer speech recognition in noise than younger participants, regardless of measurement time of day. However, a change in inhibition would be associated with measurement time of day and therefore affect speech recognition in noise, with better performance in the morning for older adults and in the evening for younger adults. Therefore, a greater age difference in speech-in-noise performance would be observed in the evening (off-peak for older adults and peak for younger adults) than in the morning.
3. All participants would be less susceptible to the effects of distracter words on a visual-distraction task when tested at their peak time of day.
4. All participants would rate the speech-in-noise and visual-distraction tasks as requiring more effort and demand at off-peak than peak measurement times of day.
5. Older adults would demonstrate poorer scores on a test of short-term memory than did younger adults, but participants tested at their peak measurement time of day would perform better than participants tested at their off-peak measurement time of day.

MATERIALS AND METHODS

Participants

Participants included two groups: 15 younger (20–28 years) and 15 older (66–78 years) native American English speaking adults. All participants had hearing within normal limits, defined as pure-tone air conduction thresholds better than or equal to 20 dB HL (re: ANSI 2010) at octave frequencies from 250 to 4000 Hz in both ears. Younger adults were required to have air conduction thresholds better than or equal to 20 dB HL at 6000 Hz, and older adults were required to have air conduction thresholds better than or equal to 40 dB HL at 6000 Hz. Only 4 of the 15 older adults had hearing thresholds of 35 or 40 dB HL at 6000 Hz in one or both ears. Mean pure-tone audiometric thresholds for each group (±1 SD) are shown in Figure 1. Participants also had word-recognition scores of 92% or higher in quiet in both ears, as measured with the recorded lists of the Northwestern University Auditory Test No. 6 (Tillman & Carhart 1966) monosyllabic word lists presented at 30 dB SL re: speech-recognition threshold. Participant selection criteria also included tympanograms with normal peak admittance (0.30–1.50 mmhos; Roup et al. 1998), normal equivalent ear canal volume (0.90–1.80 cm^3; Roup et al. 1998), and normal tympanometric width (35.80–95.00 daPa; Roup et al. 1998), and air-bone gaps less than 10 dB from 500 to 4000 Hz, suggesting the absence of middle ear pathology.

Participants were selected to have peak performance times consistent with general norms for their age groups (Intons-Peterson et al. 1998; May & Hasher 1998); therefore, all older adult participants were "morning types," and all younger adult participants were "evening types." Circadian arousal patterns

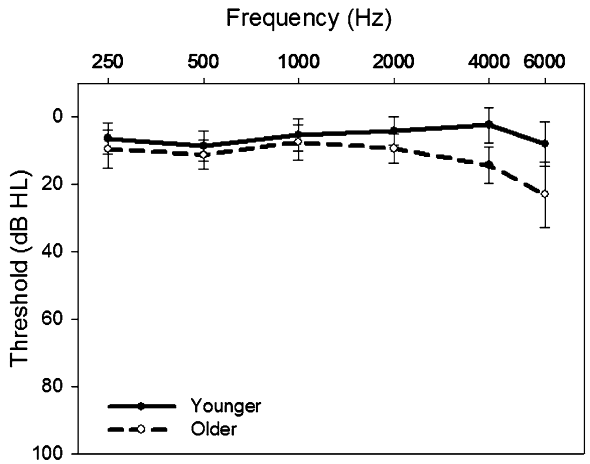

Fig. 1. Mean pure-tone thresholds (dB HL) (±1 SD) for both ears of younger participants (solid line) and older participants (dotted line), plotted as a function of frequency (Hz).

TABLE 1. Examples of each category of the visual-distraction task

Category	Target Word	Cue Words	Distracter Words
Filler	Cane	CANDY SUGAR WALKING	None
No distracter	Cookie	CHOCOLATE FORTUNE TIN	None
Leading distracter	Egg	SALAD HEAD BOILED	sandwich smart hard
Misleading distracter	Bath	ROOM BUBBLE SALTS	arena gum pepper

and time-of-day preferences for younger and older adults were determined by the MEQ (Horne & Ostberg 1976), which classifies individuals into one of the following three types: morning types (scores of 59–86), neutral types (scores of 42–58), and evening types (scores of 16–41). Individuals who did not meet MEQ norms for their age group were excluded from participation in this study. All of the individuals excluded based on MEQ scores were young adults. None of the older adults who volunteered to participate in the study were excluded based on scoring as neutral or evening types. Although a fully crossed design of Age × Morningness-Eveningness would be desirable (i.e., both younger and older morning-type groups and both younger and older evening-type groups), identifying older participants with eveningness preference is quite challenging, as underscored by the fact that all the older participants had a preference for morning. The subject group assignment used in this study is therefore consistent with numerous other studies that have investigated the effects of time of day and age (May & Hasher 1998; May 1999). It should be noted that 7 of the 15 younger participants were working professionals, and the other 8 younger participants were full-time undergraduate or graduate students. Hence, the younger group is composed of individuals with varying daily schedules. All 15 of the older participants were retired.

Stimuli and Apparatus

Two standardized tests of speech-recognition performance in noise were presented to listeners: (1) the QuickSIN test (Killion et al. 2004) and (2) the HINT (Nilsson et al. 1994). Stimuli from both tests were presented from a CD player, routed through a Madsen OB922 audiometer that was calibrated to meet American National Standards Institute (ANSI 2010) standards and were delivered binaurally through ER-3A insert earphones. The QuickSIN test consists of 12 lists of Institute of Electrical and Electronics Engineers (IEEE) sentences. Each list consists of six sentences spoken by a female talker in a background of four-talker babble. The HINT (Nilsson et al. 1994) consists of 25 lists of sentences. Each list consists of 10 Bamford–Kowal–Bench sentences spoken by a male talker in a background of speech-spectrum noise. All audiologic testing was conducted in a double-walled sound-treated booth. A Larson–Davis Laboratories 800 B sound level meter was used to verify levels of all signals.

The VDT was a slightly modified version of that described by May (1999). In this task, participants were asked to identify a target word that is semantically associated with three cue words. The cue words were presented with “distracting” (either misleading or leading) words on some trials and without any additional words on other trials; participants were instructed to ignore all distracting words. For each trial, the three cue words were presented visually as black text in uppercase print on a white computer screen background for 30 sec. Performance on this task was measured by the participant’s ability to verbally identify the target word that was semantically related to all three of the cue words. Each test administration included 50 trials that could be divided into four categories of word problems: (1) filler; (2) no distracters; (3) leading distracters; and (4) misleading distracters. An example of the components of each category is provided in Table 1, and a sample trial of each category is provided in Figure 2. The “filler” category (10 trials) presented three cue words in uppercase print that would easily generate a correct solution. This condition is included to improve participant morale, as the task was shown to be fairly difficult in pilot testing (May 1999). The “no distracter” category (10 trials) was considered to be the control category and provided three cue words in uppercase print without any distracter words; the target words in this category generally are more difficult to identify than target words in the filler category. The “leading distracter” category (10 trials) presented three cue words in uppercase print, with three leading distracter words presented simultaneously and directly below the cue words in lowercase print; these distracters served to facilitate the generation of the correct solution. Finally, the “misleading distracter” category (20 trials) presented three cue words in uppercase print, with three misleading distracter words presented simultaneously and directly underneath the cue words in lowercase print; these distracters served to interfere with the generation of the correct solution. Additional information about the task is provided in the Procedures section.

A modified version of the NASA Task Load Index self-report questionnaire (Hart & Staveland 1988) was selected to provide an estimate of perceived effort and demand required by the speech-in-noise and visual-distraction tasks. This

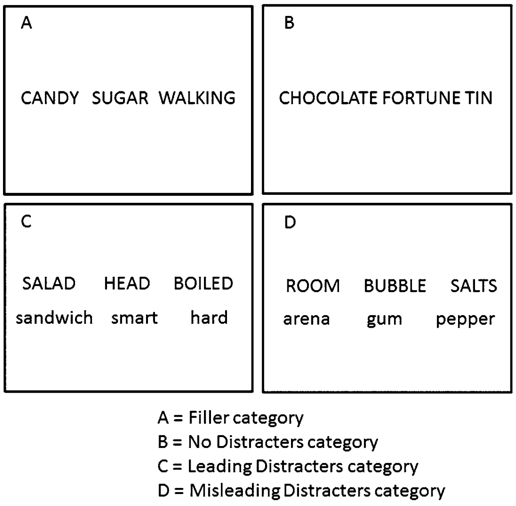

Fig. 2. Sample trial of each category of the visual-distraction task items; cue words are in uppercase print, and leading and misleading distracters are in lowercase print.

TABLE 2. Modified NASA Task Load Index subjective rating categories and corresponding index items

Category of Subjective Rating	Index Items
Mental demand	How mentally demanding were the tasks?
Physical demand	How physically demanding were the tasks? How much physical agitation, pain, or aches did you experience?
Temporal demand	How hurried or rushed was the pace of the tasks?
Performance	How well did you understand the instructions for the tasks? How successful were you in accomplishing what you were asked to do? How well did you perform when repeating speech in background noise? How many word problems did you answer correctly?
Effort	How hard did you have to work to accomplish your level of performance?
Frustration	How insecure, discouraged, irritated, stressed, and annoyed were you?

index consists of 10 questions that asked participants to rate their performance on and the perceived mental and physical demand required by the HINT, the QuickSIN, and the VDT on a 20-point visual analog scale (1 = no demand or very poor performance; 20 = total demand or perfect performance). Ratings were scored separately for each question. The questions and associated types of demand they probe are shown in Table 2. This measure was added to the study after data were collected for 6 older adults, leaving only 9 older adults and 15 younger adults to complete the index.

The digit-span scale of the revised Wechsler Adult Intelligence Scale (WAIS-R; Wechsler 1981) was chosen for this study as a measure of working memory, concentration, and short-term auditory memory. Although not the primary focus, it was included in this study to contrast the extent to which age-related differences in speech recognition in noise at different times of day might be explained by age-related differences in auditory memory versus age-related differences in inhibitory mechanisms (measured by the VDT). As reported previously (Daneman & Green 1986; Daneman & Tardiff 1987), the best predictors for specific tasks are working-memory tests that are closely tied to each particular task. The digit-span test was selected as one of several auditory tasks of working memory available (e.g., the auditory forms of the N-Back test [Kirchner 1958; Monk et al. 2011] or the Reading Span Test [R-SPAN; Daneman & Carpenter 1980; Pichora-Fuller et al. 1995]), which has no visual components. The digit-span test also was selected because it has been used in prior investigations showing a relationship between verbal working memory and recognition of degraded speech with older listeners (e.g., Schvartz et al. 2008; Vaughan et al. 2006). The test was administered according to the WAIS-R instructions. Three scores were generated for each participant: a digit-forward score, a digit-backward score, and a total digit-span score.

Procedures

Data were collected during two test sessions lasting approximately 60 min each, with no more than 2 weeks between sessions. One session was held in the morning (completed before 10:00 A.M.), and the other was held in the evening (beginning after 5:00 P.M.). Half the participants in each age group were randomly assigned to be tested first in the morning, and the other half were randomly assigned to be tested first in the evening. Participants were informed that the goal of the study was to investigate the effects of patient and procedural factors on speech-recognition ability in noise but were not explicitly told that time-of-day effects were being addressed. Preliminary measures, including the MEQ, pure-tone audiometry, word recognition in quiet, and tympanometry, were completed at the beginning of the first session.

During the first session, the ability to recognize speech in the presence of background noise was measured using two speech-in-noise tests (QuickSIN and HINT), which were administered to participants in the typical manner. During QuickSIN administration, six sentences were presented at a fixed level of 70 dB HL. Each sentence was presented at a different signal-to-noise ratio (SNR), with the initial noise level presented 25 dB below the sentence level (+25 dB SNR). For each subsequent sentence, the noise level was increased by 5 dB until the noise level for the last sentence was equal to the sentence level (0 dB SNR). Participants were given a practice list and then the QuickSIN was repeated three times using three separate six-sentence lists. The participant repeated as much of each sentence as possible. The number of key words identified correctly (of five key words per sentence) was recorded for each list. An estimate of the SNR corresponding to 50% correct sentence recognition was derived from the QuickSIN test results following procedures described by Killion et al. (2004). The number of correct key words was subtracted from the starting SNR (25 dB), and a correction factor of 2.5 dB was added to calculate the SNR required for 50% correct performance. To calculate "SNR loss," 2 dB (normal SNR) was subtracted from the individual's SNR. SNR loss was calculated for each of the three QuickSIN lists and then averaged to determine the participant's final SNR loss.

During HINT administration, 10 sentences were presented in a background of speech-spectrum noise, and the participant repeated as many words of each sentence as possible. The sentences and noise were presented to both ears in a simulated 0-degree azimuth condition. The test was administered using an adaptive procedure, where the noise level was fixed at 65 dBA, and the first sentence was initially presented at 0 dB SNR. The level of the first sentence was increased by 4 dB after each incorrect response until the listener was able to repeat correctly all words in the sentence. For the next three sentences (2–4), the presentation level of the following sentence was decreased by 4 dB if the sentence was repeated correctly and increased by 4 dB if the sentence was not repeated correctly. For sentences 5 to 10, the presentation level of the following sentence was increased by 2 dB if the sentence was repeated correctly and decreased by 2 dB if the sentence was not repeated correctly. Participants were given a practice list and then the HINT procedure was repeated three times with three separate 10-sentence lists. An estimate of the SNR corresponding to 50% correct sentence recognition was derived separately from each list using procedures outlined by Nilsson et al. (1994). The SNRs derived from each of the three lists were averaged to determine the participant's final SNR.

The VDT also was administered during the first session. Participants were tested in a quiet room, using a laptop computer. Each participant was tested on 50 trials and was given 30 sec to provide a response for each trial. They were instructed that, for each set of three cue words in uppercase print presented on the computer screen, they should verbally identify the target word that is semantically associated with all three cue words. The participants were told that, for some trials, distracter words would appear in lowercase print below the three cue words. They were informed that the distracter words would always be misleading and, therefore, would interfere with the generation of the correct solution and were instructed to ignore the distracter words when present. Before the beginning of the test, all participants were given two examples for practice: (1) cue words with distracters and (2) cue words without distracters.

At the end of the first session, participants were given the Modified NASA Task Load Index and were asked to complete all 10 items based on their subjective impressions of the session as a whole. In addition, two questions asked specifically about the perceived performance on both speech-in-noise measures combined (HINT and QuickSIN) and the VDT.

The second test session was identical to the first session but with two exceptions: (1) the digit-span scale was administered verbally to each participant at the beginning of the second test session and (2) none of the preliminary measures were repeated, except for tympanometry, which was used to document the continued absence of middle ear pathology. For the forward digit span scale, participants were instructed to repeat as many digits as possible in the order in which they were presented; for the backward digit span scale, participants were instructed to repeat as many digits as possible in the reverse order in which they were presented. Different lists of QuickSIN and HINT sentences were used in each session and the order of the lists administered to each participant was randomized. The order of the word problems for the VDT also differed for the second session. The test order (HINT, QuickSIN, and VDT) was randomized across participants, but for each participant, the test order was the same for morning and evening sessions.

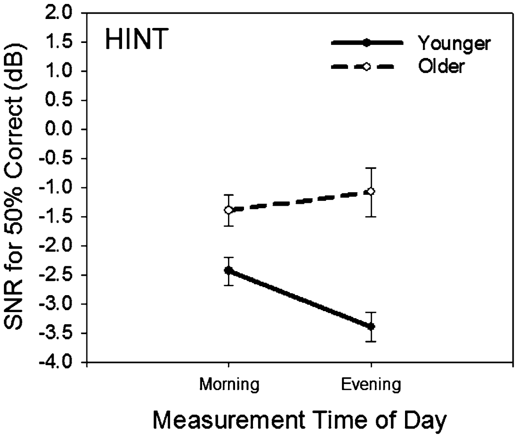

Fig. 3. Mean SNR required for 50% correct performance on the HINT for morning and evening measurement times. Participant age group is the parameter. Error bars indicate SE. HINT, Hearing in Noise Test; SNR, signal-to-noise ratio.

RESULTS

Speech Recognition in Noise

The average performance measured in the morning and evening for both age groups on the HINT and QuickSIN is shown in Figures 3 and 4, respectively. For each speech-in-noise test, a separate analysis of variance (ANOVA) using PASW Statistics 18 software was conducted with a split plot factorial design with one within-subjects factor (measurement time of day) and one between-subjects factor (age). The ANOVAs showed a significant main effect of age for HINT SNR (F[28, 1] = 26.16; $p < 0.001$) and QuickSIN SNR (F[28, 1] = 22.87; $p < 0.001$), with older adults requiring significantly more advantageous SNRs than younger adults for equivalent performance (50%). No significant main effect of measurement time of day was observed for either speech-in-noise test (F[1, 30] = 1.35; $p = 0.25$ for HINT and F[1, 30] = 0.43; $p = 0.52$ for QuickSIN). A significant interaction between age and measurement time of day was observed for the HINT (F[28, 1] = 5.42; $p < 0.05$) and the QuickSIN (F[28, 1] = 7.17; $p < 0.05$). Post hoc paired samples t tests (with the Bonferroni correction for multiple t tests applied) indicated that younger adults performed significantly better (lower SNRs) when tested at their peak (evening) than the off-peak (morning) time of day for the HINT (t[14] = –3.43; $p = 0.004$) and also for the QuickSIN (t[14] = –2.47; $p = 0.027$). The performance of older adults did not differ significantly between peak (morning) and off-peak (evening) times of day for the HINT (t[14] = –1.367; $p = 0.19$) or the QuickSIN (t[14] = –0.68; $p = 0.51$). Additional post hoc independent samples t tests (with the Bonferroni correction for multiple t tests applied) indicated that older adults performed significantly less well than did younger adults on the HINT in the morning (t[28] = –2.93; $p = 0.007$) and in the evening (t[28] = –4.74; $p < 0.001$). Older adults also performed significantly less well than did younger adults on QuickSIN at both measurement times of day (t[28] = –2.53; $p = 0.017$ in the morning; t[28] = –5.10; $p < 0.001$ in the

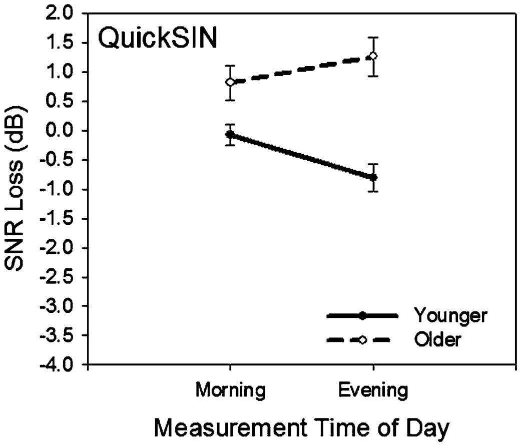

Fig. 4. Mean SNR loss measured by the QuickSIN test for morning and evening measurement times. Participant age group is the parameter. Error bars indicate SE. SNR, signal-to-noise ratio; QuickSIN, Quick Speech in Noise test.

evening). The morning age differences (*t*[28] = –2.93 for HINT versus *t*[28] = –2.53 for QuickSIN) and evening age differences (t[28] = –4.74 for HINT versus *t*[28] = –5.10 for QuickSIN) revealed a significantly larger age difference in performance on both tests in the evening than in the morning.

Independent *t* tests showed no significant differences in HINT performance between the working professionals and the students in the younger participant group at either measurement time of day (*t*[13] = 0.23; $p = 0.82$ in the morning; *t*[13] = –0.22; $p = 0.82$ in the evening). Similarly, no significant differences in QuickSIN performance were noted between the younger working professionals and the younger students in the morning (*t*[13] = –0.68; $p = 0.51$) or in the evening (*t*[13] = 1.05; $p = 0.31$). Although the lack of significant differences could be associated with a type I error because of small sample sizes for this analysis, the magnitude of differences in mean performance is so small that it tentatively suggests that there are no practical differences between groups.

Pearson product–moment correlations were computed to verify that similar patterns of results were found for both speech-in-noise tests and to determine whether correlations between performance on the HINT and the QuickSIN differed, depending on measurement time of day (e.g., peak or off-peak). Scatter plots displaying the HINT and the QuickSIN SNRs at peak and off-peak measurement times of day are presented in Figures 5 and 6, respectively. When data from all participants were included, significant positive correlations were observed between HINT and QuickSIN SNRs, both at peak ($r = 0.71$; $p < 0.001$) and off-peak ($r = 0.45$; $p < 0.01$) measurement times of day. The correlation between peak HINT and peak QuickSIN SNRs was significantly higher than the correlation between off-peak HINT and off-peak QuickSIN performance ($p < 0.005$; Steiger 1980). When correlations were examined separately within each subject group, no significant correlations were observed between peak HINT and peak QuickSIN SNRs ($r = 0.30$; $p > 0.05$) or between off-peak HINT and off-peak QuickSIN SNRs ($r = 0.16$; $p > 0.05$) among the younger participants. The older participants showed a significant positive correlation between peak HINT and peak QuickSIN performance ($r = 0.62$; $p < 0.05$) but no significant correlation for off-peak HINT and off-peak QuickSIN performance ($r = 0.37$; $p > 0.05$).

Stepwise multiple linear regression analyses were conducted separately for each speech-in-noise test using the PASW Statistics 18 software to determine the relationship between several participant factors and HINT and QuickSIN performance at peak and off-peak measurement times of day. The participant factors included in the analysis were age, total digit-span score, percentage score for misleading distracter items on the VDT (as the principal estimate of inhibition), and peak and off-peak mental demand ratings (discussed in later sections); Kleimbaum et al. (1988) noted that up to six variables could be included in a regression analysis with a sample size of 30 subjects. The results of these analyses are shown in Table 3. Age is the only variable shown to account for a significant proportion of variance in HINT and QuickSIN performance, both at peak and off-peak measurement times of day. For both speech-in-noise tests, poorer speech recognition in noise tends to occur with older participants. Older adults had significantly poorer audiometric thresholds than did younger adults at 2000 Hz (*t*[28] = –4.07; $p < 0.001$), 4000 Hz (*t*[28] = –6.78; $p < 0.001$), and 6000 Hz (t[28] = –5.06; $p < 0.001$). However, once age was controlled in the stepwise multiple regression, high-frequency pure-tone average (1000, 2000, and 4000 Hz) was not a significant

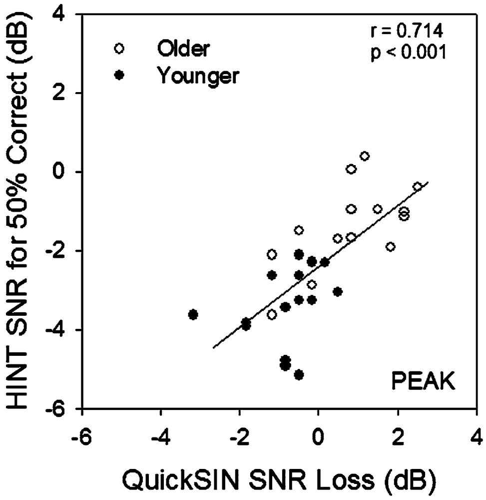

Fig. 5. Correlation between HINT and QuickSIN SNR measured at peak time of day for younger and older adults. SNR, signal-to-noise ratio; QuickSIN, Quick Speech in Noise test; HINT, Hearing in Noise Test.

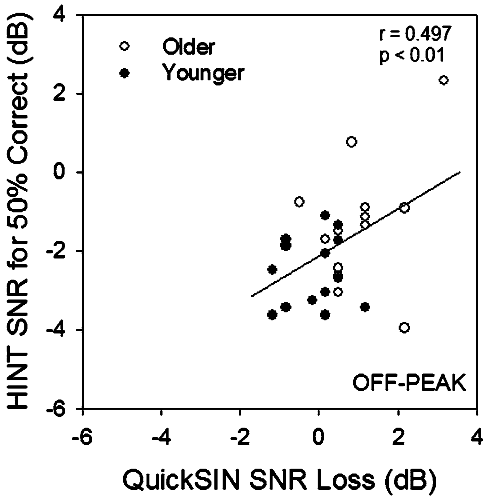

Fig. 6. Correlation between HINT and off QuickSIN SNR measured at off-peak time of day for younger and older adults. SNR, signal-to-noise ratio; QuickSIN, Quick Speech in Noise test; HINT, Hearing in Noise Test.

TABLE 3. Percentage of variance accounted for by age for HINT and QuickSIN performance at peak and off-peak measurement times of day

Dependent Variable	Variance Accounted for by Age (%)	Significance Level (*p*)
Peak HINT performance	44.1	0.000
Peak QuickSIN performance	33.4	0.003
Off-peak HINT performance	36.0	0.002
Off-peak QuickSIN performance	28.5	0.007

HINT, Hearing in Noise Test; QuickSIN, Quick Speech in Noise test.

predictor of HINT or QuickSIN performance. Neither digit-span scores (forward, backward, and total scores) nor performance on misleading distracter items on the VDT were found to be significant predictors of speech-in-noise performance.

Subjective Measures of Task Demand

Of the 10 questions on the Modified NASA Task Load Index, which rated the perceived mental and physical effort put forth for the speech-in-noise measures and VDT, the only question that yielded a significantly different rating from peak to off-peak measurement times was the question related to mental demand (Fig. 7). Participants rated the tasks as requiring significantly more mental demand when tested at their off-peak time of day than when tested at their peak time of day ($t[23] = -2.62$; $p < 0.01$). However, further analysis suggested that the younger participants were the source of this significant difference. Younger participants rated the tasks as significantly more mentally demanding at their off-peak measurement time of day (mean rating = 14.47) than at their peak time of day (mean rating = 11.87; $t[14] = -2.67$; $p < 0.05$). No significant difference was found for ratings of mental demand at peak and off-peak measurement times among older adults ($t[8] = -1.14$; $p = 0.29$), with a mean peak mental demand rating of 12.67 and a mean off-peak mental demand rating of 13.78. In addition, there was no significant age difference in mental demand ratings at either peak ($t[8] = -1.50$; $p = 0.17$) or off-peak ($t[8] = -0.15$; $p = 0.88$) measurement times of day; however, the lack of a significant age difference could be associated with a Type I error because of the relatively small number of older participants completing this index.

Visual-Distraction Task

Performance on the VDT was assessed as an independent measure of inhibitory control for younger and older subjects at peak and off-peak times of day. Statistical analyses revealed significant differences in scores between trials 1 and 2 for all categories—total score ($t[29] = -6.10$; $p < 0.001$), fillers ($t[29] = -2.24$; $p < 0.05$), no distracters ($t[29] = -2.54$; $p < 0.05$), leading distracters ($t[29] = -3.98$; $p < 0.001$), and misleading distracters ($t[29] = -3.00$; $p < 0.01$). Participants performed significantly better on the VDT during the second test session than the first test session, regardless of whether participants were tested first at their peak or off-peak time of day. Nevertheless, because the order of time-of-day of testing was randomized across participants, the learning effects observed on the VDT were assumed to be equivocal for purposes of examining time-of-day effects.

Performance on the VDT for each age group at peak and off-peak measurement times of day is shown in Figure 8. The filler category was not included in statistical analysis, because these items were included in the task simply to help with participant morale. Younger participants achieved significantly higher scores than did older participants for no distracter items and for misleading distracter items, as well as for the total VDT score, with minimal differences in performance at peak and off-peak measurement times of day. A 2 × 2 ANOVA was conducted separately for each of the three categories of the VDT and for the total score with age (younger versus older) as a between-subjects factor and measurement time of day (peak versus off-peak) as a within-subjects factor for each separate analysis. The ANOVAs showed a significant main effect of age for total score ($F[28,1] = 15.92$; $p < 0.001$) and for the "no distracter" ($F[28,1] = 19.78$; $p < 0.001$) and "misleading distracter" ($F[28,1] = 12.42$; $p < 0.005$) categories (Fig. 8). Performance on "leading distracter" problems did not differ significantly between age groups. No main effects of measurement time of day were observed for any of the VDT categories, and no significant interactions between age and measurement time of day were observed for any VDT category.

The misleading distracter items on the VDT reflect the category that most closely reflects the ability to inhibit irrelevant information. Correlation analyses were conducted, therefore, to examine the relationship between performance on the misleading distracter items and measurement time of day. Significant correlations were found at the peak time of day between misleading distracter scores and HINT scores ($r = -0.56$; $p <$

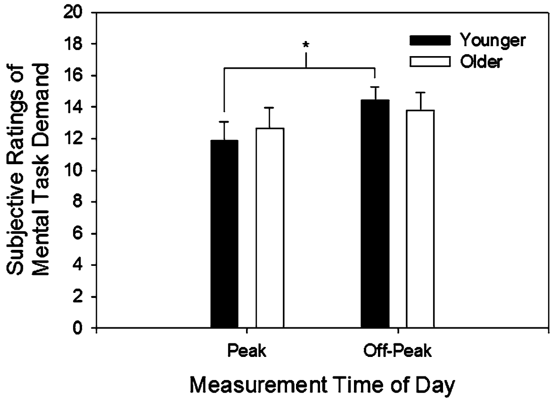

Fig. 7. Mean subjective ratings of mental task demand on the Modified NASA Task Load Index at peak and off-peak measurement times for younger and older adults. Larger numbers indicate higher levels of mental task demand. The asterisk (*) indicates a statistically significant difference in ratings of mental demand among the younger adults from peak to off-peak measurement times. Error bars indicate SE.

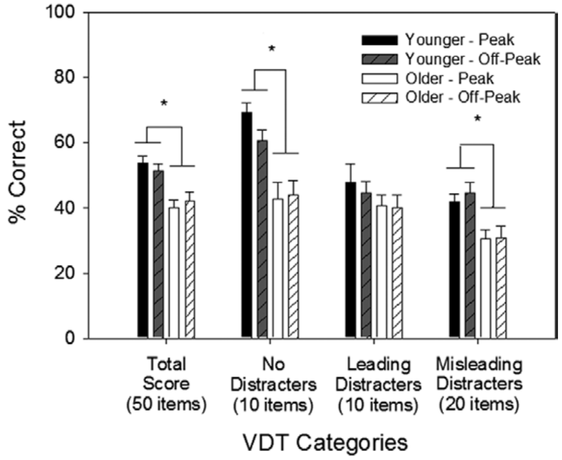

Fig. 8. Mean performance (% correct) plotted by category of visual distraction task for younger and older adults at peak and off-peak measurement times. Asterisks (*) denote a statistically significant difference in performance between younger and older adults. Error bars indicate SE. VDT, visual-distraction task.

0.005) and between misleading distracter scores and QuickSIN scores ($r = -0.477$; $p < 0.01$). The negative correlations suggest that individuals with higher visual-distraction scores (i.e., better inhibition of distracter items) had lower SNRs on the HINT and QuickSIN (i.e., better thresholds in noise). Correlations at off-peak measurement times between the VDT and speech-in-noise scores were not significant ($p > 0.05$, all correlations).

Digit-Span Scale

The final analysis compared the performance of the two age groups at two measurement times (peak and off-peak) on the digit-span scale, a measure of short-term memory. Results from the three measures derived from the digit-span scale (forward digit, backward digit, and total digit-span score) were analyzed separately using ANOVAs, with age and measurement time of day as between-subjects variables. No significant main effects of age ($p > 0.05$) or measurement time of day ($p > 0.05$) were found for any of the three measures, and there was no interaction between age and measurement time of day ($p > 0.05$). Perhaps another kind of measure of working memory span (such as the R-SPAN or the SICSPAN) would have been more sensitive to individual differences, as well as age and measurement time-of-day differences (Sörqvist & Rönnberg 2012).

DISCUSSION

This study demonstrated that measurement time of day interacted with effects of age to influence speech recognition in noise. Although older adults with normal hearing required a more advantageous SNR to achieve equivalent performance to younger adults with normal hearing, these age-related differences were larger in the evening than in the morning. This exaggerated age effect in the evening was attributed, in large part, to better speech-recognition ability in noise among younger adults when testing was conducted at the time of day corresponding with their peak level of circadian arousal (evening). Older adults did not exhibit significant measurement time-of-day effects.

Age Effects on Speech Recognition in Noise

The finding that older adults have more difficulty understanding speech in the presence of noise than younger adults is consistent with other research on speech recognition among older listeners with normal or near normal auditory sensitivity (e.g., Dubno et al. 1984; Pichora-Fuller et al. 1995; Tun & Wingfield 1999). Although the older participants exhibited slightly poorer thresholds in the higher frequencies, this was not considered a significant contributor to speech-recognition performance in the present study because the limited bandwidth of the insert earphones likely minimized between-group threshold differences at the highest frequencies. Nevertheless, age-related deficits in suprathreshold processing abilities not reflected in pure-tone thresholds (such as reduced frequency selectivity or impaired temporal processing) could have contributed to poorer speech recognition in noise, although the mechanisms underlying these effects remain unclear. For the present study, these presumed deficits would not likely explain time-of-day differences in performance.

Another possible source of age-related speech processing difficulties in noisy environments is inefficient inhibition of irrelevant stimuli compared with younger listeners (Tun et al. 2002; Li et al. 2004). Reduced suppression of irrelevant information requires the older listener to devote cognitive resources to processing this irrelevant information. As a result, the cognitive processing of target speech information may be impacted negatively. In the current study, it was predicted that age effects would be greater for the QuickSIN test compared with the HINT, because the QuickSIN test in multi-talker babble might require more inhibitory mechanisms to reduce the effects of energetic and informational masking, whereas the HINT sentences in steady-state noise might require less. However, the present results showed that the older participants consistently performed more poorly than the younger participants on both speech in noise tests. The discrepancy between predicted and observed findings may be related to specific methodological details, such as relative differences in the acoustic characteristics of the background noises, type of adaptive procedures used, and the level of difficulty of the speech materials.

Measurement Time-of-Day Effects on Speech Recognition in Noise

Younger adults performed better on speech-in-noise tasks when tested at their peak time of day (evening) than when tested at their reported off-peak time of day (morning), which is consistent with previous studies in vision that investigated changes in inhibition with measurement time of day. However, the performance of older adults on the same speech-in-noise tasks did not change significantly from peak (morning) to off-peak (evening) measurement times. This lack of time-of-day effects among older adults is not consistent with previous research on inhibition and measurement time of day in vision (e.g., May & Hasher 1998; May 1999). Finally, a greater age difference in speech recognition in noise was observed in the evening than in the morning, despite the fact that no significant measurement time-of-day effects were documented among the older adults. This finding follows the pattern seen in many other studies investigating age and time-of-day effects on inhibitory control in the visual modality.

The reason for the lack of a time-of-day effect among older participants is unknown. One possible explanation is that time-of-day effects do not occur for older adults on an auditory task, despite their common observation on visual tasks. A second possibility is that the off-peak time of day selected for testing the older participants (5:00–6:00 P.M.) may not have been optimal for an auditory task. For example, it is possible that older participants could have gotten a "second wind" around the time of the evening test session in this study; perhaps, testing later in the evening (7:00–8:00 P.M.) would have been a more optimal time to measure an effect of time of day. Finally, the older adults who participated in this study all had normal hearing sensitivity and excellent speech-recognition ability in noise. It is possible that this exceptional group of older listeners was not representative of a typical older population and, therefore, did not show the expected measurement time-of-day effects. A follow-up investigation to examine time-of-day effects among older adults with hearing loss may prove valuable in disentangling time-of-day effects and the effects of cumulative fatigue because of listening effort demands on auditory tasks.

Although changes in inhibition with time of day may be a cause of speech-recognition performance differences among younger adults in the morning and evening, other factors may also influence younger adults' improved performance in the evening (compared with the morning performance). For example, differences in lifestyle associated with age could have been a contributing factor. The younger participants were either working professionals or full-time undergraduate or graduate students and may have performed worse in the morning than in the evening because of insufficient or poor sleep before the morning test session. Approximately one-third of young adults report chronic sleep deprivation, which is associated with fatigue and reduced performance on a wide range of psychomotor tasks (Bonnet & Arand 1995). In contrast, all of the older participants were retired and may not experience sleep fatigue because older adults on average require 1.5 hr less nocturnal sleep than younger adults (Klerman & Dijk 2008). Such factors as sleep patterns and fatigue are difficult to control in a single study, but future research may seek to isolate these factors to determine their significance in speech-in-noise performance at different times of day.

Subjective Ratings of Task Demand

Younger adults rated the speech-in-noise tasks and the VDT as requiring significantly more mental demand when tested at their off-peak than peak time of day. This finding is consistent with measures of speech recognition in noise, because younger adults also showed poorer performance on HINT and QuickSIN when tested at their off-peak time of day. The subjective ratings of the older adults did not differ significantly from peak to off-peak measurement times, and this follows the lack of a significant difference in performance with measurement time of day on the HINT and QuickSIN among older participants. The absence of a significant difference in subjective ratings of task demand with time of day simply may validate the speech-in-noise results for this older age group; perhaps no changes to inhibition occurred among the older adults, as suggested by the lack of performance difference with measurement time of day. Alternatively, the absence of a significant difference in subjective ratings from peak to off-peak times may be a result of the lack of power among this older age group because data were collected from only nine older adults.

No age differences were observed in ratings of mental demand at either peak or off-peak measurement times of day. This finding is not consistent with measures of speech recognition in noise, where the older participants showed significantly poorer performance on the HINT and the QuickSIN than the younger participants. Other studies have documented inconsistencies in age effects observed on performance measures versus subjective ratings of mental demand. For example, Larsby et al. (2005) found no significant age differences in the perceived effort required to complete a cognitive test battery designed to assess skills necessary for speech recognition, despite finding that older adults performed significantly worse on the cognitive tasks than younger adults.

One possible explanation for the disconnect between performance and ratings of task demand among the older participants is that older adults may be less aware of performance deficits than younger adults and therefore report less perceived effort for certain tasks. For example, older adults report less disability resulting from mild-to-moderate hearing loss than younger adults with an equivalent degree of hearing loss on scales of hearing disability (e.g., Gordon-Salant et al. 1994).

Visual-Distraction Task

Although older adults performed significantly poorer than younger adults on most categories of the VDT, the performance of both groups on this measure was not affected by the measurement time of day. Performance was expected to be better with "leading distracters" and worse with "misleading distracters" than for "no distracters," especially if the individual was paying attention to the distracter words, which would occur at the off-peak time of day (May 1999). The lack of a time-of-day effect on the VDT in this study could explain the lack of a time-of-day effect on speech recognition in noise among the older listeners. It is possible that the VDT is an adequate measure of inhibition in this study, and for this sample of older participants, inhibition did not significantly change with measurement time of day. An alternative explanation is that the VDT used in this study is not a sensitive measure of inhibition. Perhaps a different task (e.g., the Stroop task; Stroop 1935) would provide a more sensitive estimate of inhibition and reflect changes in inhibition at different times of day, especially for older listeners.

Performance on the misleading items of the VDT was correlated with performance on both speech-in-noise tasks at the peak time of day, but not at the off-peak time of day. Thus, at the peak time of day, participants' ability to inhibit the influence of distracting visual information on the semantically loaded VDT was associated with their ability to ignore irrelevant auditory information in the form of background noise or babble. If the ability to suppress the effects of unwanted semantic information was a common and important link between the two tasks, then it might be predicted that the correlation between the VDT and QuickSIN would be higher than that between the VDT and HINT. This was not observed. Rather, the significant correlations observed between performance on the VDT and both speech-in-noise tasks suggests that a more generalized inhibitory mechanism is invoked for a speech processing task in the presence of a distracter presented in the same modality (visual or auditory) at the peak time of day. That a significant correlation between performance on the VDT and either speech-in-noise task was not observed at the off-peak time of day provides support for the notion that inhibitory mechanisms are invoked less or play a less important role in speech-recognition performance at off-peak times. Future examination of this issue should use a visual-distracter task in which the time constraints for processing are comparable to those required during a speech-recognition task, which may elicit more comparable effects of inhibition or lack thereof across modalities at different times of day.

Ideally, future research on this topic should include younger participants who are "morning-type" individuals and older participants who are "evening-type" individuals to distinguish completely age effects from measurement time-of-day effects. However, this comparison is often not carried out in time-of-day studies because of difficulty recruiting older participants who are not morning-type individuals. This study was no exception, because all older adults who met age and hearing inclusion criteria were scored as morning-type individuals on the MEQ. In addition, older participants may be tested at later times in the evening to determine if testing between 5:00 and 6:00 p.m. was not late enough in the evening to observe a measurement time-of-day effect on these tasks among older adults. Future studies may want to investigate the sleep patterns of participants for the nights before testing to ensure that poorer performance is not related to the amount or quality of sleep received by participants before the morning sessions. The relationship between speech recognition in noise, aging, and measurement time of day requires further exploration to determine other possible factors contributing to this phenomenon.

SUMMARY AND CONCLUSIONS

To date, this is the first study to demonstrate significant measurement time-of-day effects on speech recognition in noise. Younger adults performed significantly worse on two different speech-in-noise tasks at their reported off-peak time of day (morning) than at their reported peak time of day (evening) and provided higher ratings of task demand at their reported off-peak measurement time of day. Older adults did not demonstrate significant measurement time-of-day effects on either task. However, age-related differences in performance were larger in the evening than in the morning. Finally, performance on a visual-distraction task was significantly related to speech-recognition performance in noise at the peak time of day but not off-peak time of day, suggesting that improved inhibition at a listener's peak time of day is linked to better speech-recognition performance in noise.

These findings have important implications for speech-in-noise testing, both clinically and in research. Clinicians may want to consider testing younger adult patients at baseline and in subsequent outcome measures at the same time of day. Researchers may contemplate determining if participants are "morning types" or "evening types" and to report the time of day that participants are tested. This may be particularly important when comparing performance on auditory tasks between groups of younger and older adults, because greater age differences may be found if participants are tested later in the day. Although it remains unclear the extent to which these time-of-day differences in speech recognition in noise are a direct result of changes in inhibitory control associated with measurement time of day, this study provides compelling evidence that measurement time of day is a factor that can have a significant effect on speech recognition in noise, at least among younger adults.

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The authors declare no conflicts of interest.

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