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Effect of Hospital Noise on Patients' Ability to Hear, Understand, and Recall Speech

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Abstract: Speech intelligibility and recall were examined in normally hearing and hearing-impaired hospitalized patients. Fifty-two participants completed testing in a sound-attenuated booth. While listening to a recorded male speaker talking at conversational level, participants were asked to identify and remember the last (key) word in each of a series of five sentences presented in hospital noise with or without voices at three decibel levels (59, 64, and 69 dBA). Noise level and sentence context had the largest impact on key word identification ($p < .001$). Noise level had the largest impact on key word recall ($p < .001$). Type of hospital noise and hearing loss also significantly influenced performance on both measures. These findings have implications for healthcare providers communicating with hospitalized patients. Res Nurs Health 36:228–241, 2013

Keywords: cognition; communication; context; health facility environment; hearing loss; inpatients; mental recall; noise; speech intelligibility

Hospitals are noisy places, and a variety of noise generators contribute to the cacophony: paging systems, patient call bells, telephones, computer printers, ice machines, televisions, carts, and clipboards, to name a few (Lawson et al., 2010; MacKenzi & Galbrun, 2007; Pope, 2010). In addition, persistent conversations and hospital equipment alarms contribute to high noise levels and complexity in the acoustic environment (Edworthy & Hellier, 2005, 2006). It is not known what impact this noise may have on patients' ability to hear, understand, and recall what is said to them by healthcare providers. Therefore, the purpose of this study was to determine the impact of hospital noise and voices on an inpatient population that included

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patients with normal hearing and those with mild to moderate hearing loss.

Effects of Noise on Health

In 2007, the Center for Health Design and the Robert Wood Johnson Foundation (Joseph & Ulrich, 2007) published a white paper in which they reviewed "how different aspects of sound—noise, speech privacy, speech intelligibility, and music—impact patient and staff outcomes in healthcare settings and the specific environmental design strategies that can be used to improve the acoustical environment of healthcare settings" (p. 2). They determined that negative effects of hospital noise on patients included physiological impairment and inadequate communication and speech intelligibility.

Numerous researchers over the last 35 years have linked hospital noise, in decibel ranges far below those known to damage hearing, to a variety of unhealthy physiological outcomes, such as sleep disturbances, elevated blood pressure, increased heart and respiration rates (Baker, Garvin, Kennedy, & Polivka, 1993; Lusk, Gillespie, Hagerty, & Ziemba, 2004), diminished immune responses (Fife & Rappaport, 1976), increased salivary cortisol levels (Hu, Jiang, Zeng, Chen, & Zhang, 2010), and increased awareness of esophageal acid reflux (Fass et al., 2008). Despite the varied quality of individual studies, the findings as a whole provide a compelling narrative of the negative physical effects of hospital noise on patients' physiological well-being.

Effect of Noise on Communication and Cognition

Communication is influenced by a multitude of factors; some but not all of them are associated with sound. Vocal expression or "emotional prosody" carries important information (Schirmer, Kotz, & Friederici, 2002). The complexity of what is being expressed and its frame of reference or context play an increasingly important role with increasing age of the listener (Pichora-Fuller, 2003; Pichora-Fuller & Souza, 2003). In addition to the spoken word, visual facial cues are universally understood to convey emotions such as happiness, sadness, fear, anger, and disgust (Etcoff & Magee, 1992). Gestures, gaze, and other forms of body language contribute important information related to intent (Allison, Puce, & McCarthy, 2000). In addition to these influences, the acoustic environment where communication takes place is always a factor but is rarely acknowledged in studies of communication (Beagley, 2011; Happ et al., 2011; Hemsley, Balandin, & Worall, 2012; Weitzel et al., 2011).

Speech intelligibility is influenced by pronunciation, the distance between talker and listener, the speech sound level, and the characteristics and sound level of interfering noise (Berglund, Lindvall, & Schwela, 1999; Beutelmann & Brand, 2006; Duquesnoy, 1983; Hallgren, Larsby, Lyxell, & Arlinger, 2005; Kobayashi, Morimoto, Sato, & Sato, 2007; Olsen, 1988; Rhebergen, Versfeld, & Dreschler, 2006; Shafiro & Gygi, 2007). Noise makes it more difficult to distinguish speech, especially as people age (Hallgren, Larsby, Lyxell, & Arlinger, 2001; Kidd, Mason, & Gallun, 2005). The higher prevalence of hearing loss in older populations further complicates communication in noisy environments (Pichora-Fuller, Schneider, & Daneman, 1995; Schneider, Daneman, & Pichora-Fuller, 2002).

To achieve optimal intelligibility in listeners with normal hearing, a difference of at least 15 dBA between the sound level of speech and the sound level of the interfering noise—called the signal-to-noise ratio (SNR)—is necessary in public indoor spaces (Kobayashi et al., 2007). As background noise levels increase, people naturally raise their voices to be heard. As vocal effort increases, clarity decreases, leading to a spiral effect of increasing volume and diminished quality of speech intelligibility (Kobayashi et al., 2007). The sound pressure level of conversational speech is approximately 60 dBA, so background noise levels greater than 45 dBA will impair speech communication. For vulnerable groups, such as adults over 60 years of age, even lower background levels are needed (Pichora-Fuller & Souza, 2003).

In addition to its effects on physiology, communication, and intelligibility, noise can affect the performance of cognitive tasks. Although noise can be stimulating, resulting in improved performance of simple tasks in short time frames, performance of more complex tasks deteriorates substantially in the presence of noise, particularly in aged individuals (Pichora-Fuller, 2003). The cognitive tasks most affected by noise include reading, attention, memorization, and problem-solving, even when the competing noise is not particularly loud (Akhtar, Weigle, Cheng, Toohill, & Berens, 2000; Bayo, Garcia, & Garcia, 1995; Murthy, Malhotra, Bala, & Raghunathan, 1995; Persson Waye, Ryherd, Lindahl, & Bergbom, 2008; Simmons, Graves, & Flynn, 2009; Venetjoki, Kaarlela-Tuomaala, Keskinen, & Hongisto, 2006). These effects have been studied in healthcare providers but, to our knowledge, not in hospitalized patients.

Among cognitive tasks potentially affected by noise, speech understanding and recall are of particular importance in the hospital environment because patients often receive extensive healthcare education and instruction during hospitalization. There is ample evidence, as cited earlier, that noise at decibel levels significantly lower than those recognized to damage hearing can cause significant physiological harm to hospitalized patients. To date, there are no studies of the impact of those levels on verbal communication with patients in that acoustic environment.

The combination of high hospital noise levels and the importance to health outcomes of speech understanding and recall during hospitalization suggests that it would be useful to investigate the extent to which both normally hearing and moderately hearing-impaired patients have difficulty hearing, understanding, and remembering what is said to them in background noise typical of medical/surgical hospital wards. Consequently, this study was designed to have real-world implications for hospitalized patients' ability to hear, understand, and recall communications with their healthcare providers.

The specific aims were (1) to examine the extent to which noise typical of nursing units reduces speech intelligibility and impairs word recall in acutely ill, hospitalized patients, and (2) to quantify the severity of reduced performance associated with age, familiarity with the healthcare setting (measured by the number of hospital admissions), hearing status, and health status (measured by number of medications prescribed on the day of testing).

Methods

Design and Sample

The study design was prospective and each participant served as his or her own control. The study was approved by the local Institutional Review Board (IRB) on May 6, 2008. Acutely ill inpatients on medical/surgical hospital wards at a Veterans hospital in the Pacific Northwest who were more than 18 years of age and had either normal hearing or mild to moderate hearing loss were eligible to participate. Patients who were physically or cognitively unable to participate were excluded, as were patients with documented aggressive behavior, patients undergoing detoxification, patients who were not native English speakers, and those with auditory disorders such as Meniere's disease.

Study flyers were included in admission packets and posted on the inpatient units, allowing inpatients the opportunity to volunteer to participate. Study staff visited one or more of the four medical/surgical hospital wards on weekday mornings and conferred with nurses to determine whether potentially eligible patients were available. Following a review of medical records to further determine eligibility, permission was obtained from the patient's provider to invite the patient to participate. The patient's nurse was consulted again to confirm the patient's availability for 2 hours of testing off the unit, and the study audiologist then described the study and obtained informed consent. Extreme caution and care were used when recruiting inpatients in order to insure their safety while off the ward, and to insure that participation would not adversely affect their health.

Procedures

Study test development. The target speech stimuli were derived from the Revised Speech-Perception-in-Noise test (R-SPIN) (Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984), which consists of eight separate forms of 50 recorded sentences spoken by the same male speaker. Each sentence has a final key word that the listener is asked to identify.

One half of the sentence in each form is "high-context," that is, contains information that aids a listener in properly guessing the final key word. The remaining half is "low-context" and does not contain such information. Comparison of performance in high versus low contexts allowed the measurement of the benefit of a frame of reference. Familiarity, as described by Pichora-Fuller et al. (1995), has been found to be a significant aid to understanding for older listeners. Participants never heard the same sentence twice, but some target words were repeated across contexts for the same listeners. Examples of high- and low-context sentences are shown in Figure 1. The R-SPIN sentences

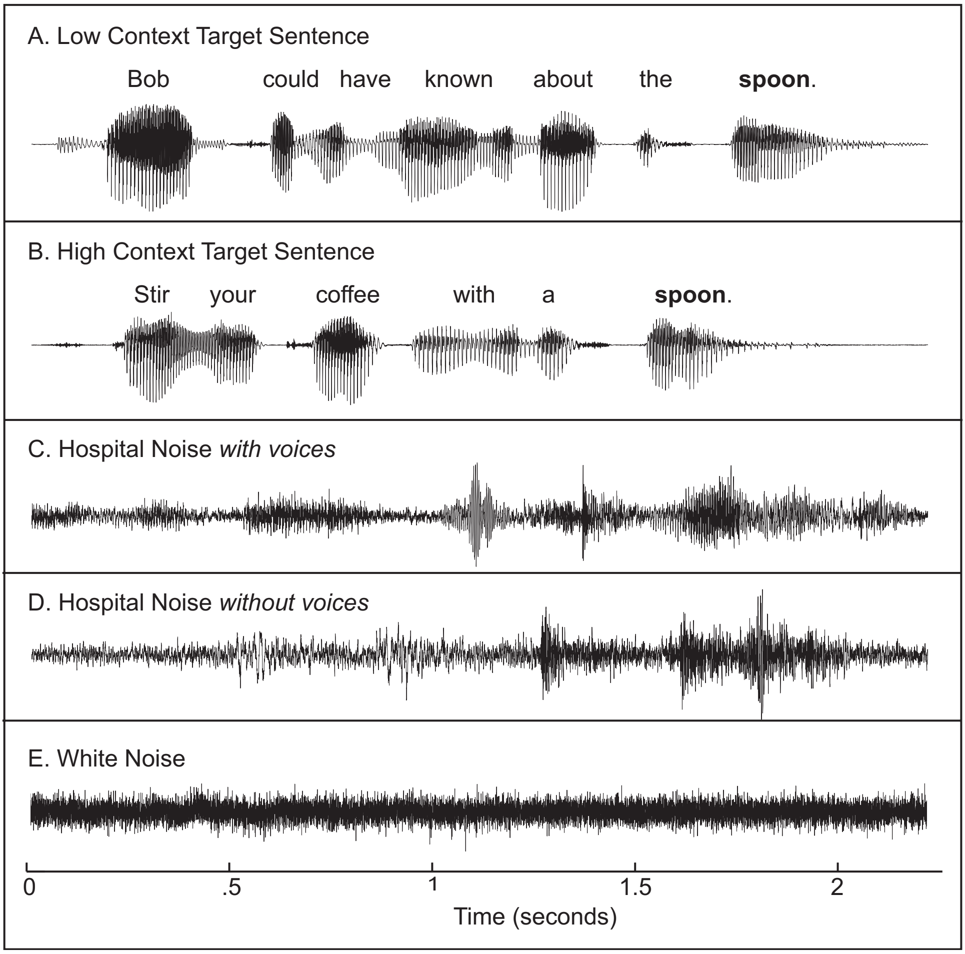

FIGURE 1. Examples of study waveform files allowing comparison of target words used in low and high context sentences, of hospital noise with and without voices, and white noise. Each example displays sound heard over 2.25 seconds.

were presented at an average level of 60.5 dBA, which is equivalent to normal conversational levels in moderate background noise (Olsen, 1988).

For this study, the R-SPIN background noise was replaced with noise recorded on one of the medical/surgical units where inpatients were later recruited to participate in the study. Digital recordings were first edited to remove all sensitive information, such as patient names or other identifying information. The remaining waveforms were then edited and combined to create 3-second hospital noise recordings in which multiple sound elements were present at all times during the recording. Half of the edited recordings contained people's voices (in addition to the background noises), while the other half contained only the background noises. The total amplitude of each noise recording was adjusted to have the same long-term average sound pressure level regardless of whether or not voices were present. Example waveforms corresponding to each type of hospital noise are shown in Figure 1.

Hospital noise recordings were presented at three levels to determine whether increasing decibel levels were associated with progressively worse performance: Low (59 dBA), potentially achievable in a hospital unit; medium (64 dBA), reflecting actual measured average levels (Pope, 2010); and high (69 dBA), which is experienced as approximately twice as loud as the low level of 59 dBA.

White noise was used in one of the test conditions as a distraction masker for all participants. The white noise had the same average sound pressure levels as the hospital noise used in the other testing conditions, but because the energy was distributed across all frequencies (the definition of white noise), measurements using an A-weighted sound level meter (dBA) were 5 dB greater for the white noise than those for the hospital noise. The differences in measurement illustrate that white noise is better than environmental noise at masking speech. White noise is constant, whereas environmental noise is episodic and contains variations in sound level over time, even after it has been edited to ensure that similar numbers of sound events occur throughout the recording. The white-noise test condition was included to provide evidence that all of the study participants responded similarly to a constant condition.

Data collection. Data on participants were collected from electronic medical records, an audiology exam, and documentation of participants' verbal responses during speech intelligibility and recall tests conducted by the study audiologist. Data on race and ethnicity were not collected because the overwhelming majority of Veterans at the medical center were white and non-Hispanic. There is no evidence or physiologic reason that race or ethnicity would influence study outcomes.

The study audiologist walked with or pushed the wheelchair of the participant to the audiology test booth and insured that the participant was returned to his or her hospital ward safely after the testing. Testing was immediately stopped and the patient returned to the ward if any change in health status was noted or reported, or if the participant was called back to the unit due to medical necessity. All participants who provided informed consent ($n = 82$) were compensated with $20 for their participation, whether or not they completed the test.

All enrolled participants had a 20-minute audiometric evaluation. Participants were excluded from further testing if the audiometric evaluation revealed more than one clinically significant air-bone gap (greater than 10 dB) in the test ear at frequencies ranging from 250 to 4,000 Hz. They were also excluded if the exam revealed otologic disease or an abnormal tympanogram in the test ear. Normal hearing was defined as pure-tone audiometric air-conduction thresholds in the test ear no poorer than 25 dB HL, averaged at 500, 1,000, 2,000, and 4,000 Hz. Mild to moderate sensorineural hearing loss was designated as pure-tone air-conduction thresholds ranging from 26 to 60 dB HL in the test ear, at the average of those same audiometric frequencies, based on a commonly used classification system (American Speech-Language-Hearing Association, 2011).

Each participant was tested individually while seated in a sound-attenuated booth. The study audiologist informed participants that they would hear recordings of a person speaking short sentences, and that their task was to identify the last word in each sentence. They were also instructed to remember the words they identified and told that they would be prompted to recall these words following the presentation of every fifth sentence. Participants were given the opportunity to ask questions and take breaks as necessary. Participants spoke their responses to the study audiologist, who documented them in real time.

Stimuli were presented monaurally through Etymotic ER-2 insert earphones (Etymotic Research, Elk Grove Village, IL) using an ER 10–14 ear tip. If hearing was symmetrical, the participant's right ear was used for testing. When hearing was asymmetrical, the better hearing ear was tested, except in the rare case when the better ear did not qualify based on the audiometric exam and study inclusion criteria. (A hyper-compliant tympanic membrane would be one reason for an ear being disqualified.)

A brief practice session was conducted, consisting of five sentences without any background noise (quiet condition), followed by five sentences presented with white noise, and finally five sentences presented with hospital noise with voices. The experimental testing followed the same order (quiet, white, hospital), and each noise condition was tested in a block of three sets (low, medium, high noise levels) of five sentences.

The performance of all the participants was assessed first in the quiet and then in the white noise test conditions. This was carried out to determine whether the participants who were assigned to listen to hospital noise and those assigned to listen to hospital noise with voices performed similarly when the listening conditions were the same. This assessment also determined the variability in performance associated with hearing loss and with key word context. Finally, the participants' performance in key word identification and recall was measured in either the hospital noise or hospital noise with voices condition.

As a requirement for continuing the testing, participants had to identify at least 80% of the key words (a minimum of 12 correct responses out of 15) in the initial quiet condition.

Participants who were unable to identify most of the key words in quiet would have too small a margin of change to measure in the other test conditions.

As shown in Table 1, participants began testing in quiet, followed by sentences presented in white noise. Three sets of 5 sentences were presented, first with a low, then medium, and finally high level of background white noise, for a total of 45 sentences. Each participant was then assigned alternately to listen to sentences in hospital noise presented at the low, medium, and high levels, either without interfering voices ($n = 27$), or with interfering voices ($n = 25$). In every condition, 6–9 of the 15 sentences were low-context and the remainder were high-context sentences.

At the conclusion of the hospital noise condition, a final quiet condition was completed to determine whether participants were fatigued by the testing (determined by performance significantly worse than it was in the first quiet condition). These data also were used to assess whether the participants "learned" the test (determined by performance significantly better than in the first quiet condition).

Participants were given credit for remembering their responses after a set of five sentences, even if the key word was initially identified incorrectly. Thus, it was possible to get a higher score on recall than on key word identification. Participants were encouraged to guess if unsure of the key word.

Data Analysis

Analyses were carried out in SPSS version 20.0. Summary statistics were calculated to describe demographic information and participant characteristics, including age, hearing status, number of admissions to the medical center, and number of medications prescribed the day of testing.

In order to determine the impact of the two types of hospital noise (with or without voices), and the potential interactions with hearing loss and high- versus low-context carrier sentences, a series of between-participants analyses of variance (ANOVA) were conducted. Using participant as a covariate accounted for the variability between participants, independent of the effects of the test conditions.

Results

Study Participants

Eighty-two (82) Veteran inpatients were recruited from the four medical/surgical hospital wards and enrolled from November 2009 through November 2010. Of those enrolled, 13 (16%) participants were excluded: 8 did not meet study eligibility criteria based on their audiology history or exam, and the remaining 5 had physical problems or were called back to their unit, leaving 69 participants for study testing. Seventeen (25%) of the participants who appeared to be eligible were subsequently excluded because they were not able to identify at least 80% of the key words in the initial quiet testing condition. Of the 69, 52 participants (75%) had complete data that could be analyzed.

Table 2 shows the characteristics of those 52 study participants compared to the estimated mean for medical/surgical patients hospitalized during the study period. Study participants were, on average, younger (55 vs. 65) and had

Table 1. Sequence, Sound Pressure Levels, and Duration of Test Conditions

Test Order in Sound Booth	Average Decibel Level (dBA)	Time in Minutes
1. Audiometric exam		20
2. Quiet (pre-test)		5–10
3. White noise (low)	64	5–10
4. White noise (medium)	69	5–10
5. White noise (loud)	74	5–10
6. Hospital noise (or noise with voices) (low)	59	5–10
7. Hospital noise (or noise with voices) (medium)	64	5–10
8. Hospital noise (or noise with voices) (loud)	69	5–10
9. Quiet (post-test)		5–10
Total test time		60–90

Note: Average sound pressure level of target speech presenting key words was 60.5 (dBA).

Table 2. Characteristics of Participants Recruited From Medical and Surgical Units at a Veterans Medical Center Compared to All Inpatient Medical/Surgical Patients During the Study Period

	Inpatients on Average Weekday on Study Units (N = 116)				Participants Who Completed Testing (N = 52)			
	n	%	Mean	(Range)	n	%	Mean	(Range)
Male	108	94			49	94		
Hearing-impaired	95	81.9 ± 3.1[a]			13	25		
Age in years			64.2	(23–93)			54.0	(27–29)
Hospital admissions			4.7	(1–31)			3.1	(1–14)
Medications			NA				13.5	(4–24)

Note: NA, not available.
[a]Estimate based on mean age in data from National Health and Nutrition Examination Survey 1999–2006 (Folmer et al., 2011).

fewer prior hospitalizations than the average medical/surgical patients hospitalized during the study period.

Mild to moderate hearing impairment was a factor in study participation. Participants who had hearing impairment were on average older (65 vs. 52, $p < .001$) and had more hospital admissions (6 vs. 3, $p = .019$). Of the 69 who were fully eligible prior to testing in the sound booth, 40 had normal hearing and 29 had hearing impairment. Of the 17 participants who were excluded because they were unable to identify at least 80% of the key words in the initial quiet condition, only one had normal hearing, leaving 13 (25%) with mild to moderate hearing impairment in the group of 52 for whom all data were available for analysis. As can be seen in Table 3, the 17 excluded were older (68 vs. 55, $p < .001$) and had double ($p = .019$) the number of hospital admissions of the other 52 participants who completed testing.

Test Conditions

Quiet test condition. A between-participant ANOVA with four factors (context, repeated testing, hospital noise group, and hearing loss) and one covariate (participant) was conducted to measure performance in key word identification. As shown in Table 4, both context and hearing loss significantly influenced performance. Participants with hearing loss were more likely to be influenced by context. In addition, for those participants whose performance differed most between initial and repeated testing, context had a larger impact on performance as well. Average performance in key word identification across sentence context is shown in Figure 2.

Whether or not the participants identified the key words correctly, recall of the words identified was examined. (Because participants were credited with correctly recalling misidentified key words, the association of performance

Table 3. Characteristics of Participants Who Passed Audiology Exam But Were Excluded From Testing and Participants Assigned to Testing Conditions of Hospital Noise or Hospital Noise With Voices

	Excluded (n = 17)				Assigned to Hospital Noise (n = 27)				Assigned to Hospital Noise with Voices (n = 25)			
	n	%	Mean	(Range)	n	%	Mean	(Range)	n	%	Mean	(Range)
Male	17	100			26	96			23	92		
Hearing-impaired	16	94			6	22			7	28		
Age in years			68.0	(52–80)			53.8	(28–66)			54.3	(27–79)
Medications			13.6	(3–28)			12.7	(5–23)			13.2	(4–24)
Hospital admissions			6.3	(1–31)			2.6	(1–13)			3.4	(1–14)

Note: Excluded participants failed to identify ≥80% key words in quiet testing condition.

Table 4. Significant Associations of Context, Noise Level, Hospital Noise Group, and Hearing Loss With Identification and Recall of Key Words in Between-Subjects ANOVA

Condition	Test	Factor	*df*	*F*	η_p^2	*p*
Quiet	Intelligibility	Context	1	43.297	**.185**	<.001
		Hearing Loss	1	20.754	.098	<.001
		Context × Hearing Loss	1	15.761	.076	<.001
		Context × Repeated Testing	1	5.029	.026	.026
		Error	191			
	Recall	Hearing Loss	1	5.137	.051	.026
		Error	95			
White noise	Intelligibility	Participant	1	7.796	.026	.006
		Noise Level	2	129.598	**.475**	<.001
		Context	1	227.224	**.491**	<.001
		Noise Level × Context	2	85.297	**.373**	<.001
		Hearing Loss × Noise Group × Context	1	4.777	.016	.030
		Error	287			
	Recall	Noise Level	2	26.765	**.272**	<.001
		Error	143			
Hospital noise	Intelligibility	Participant	1	8.878	.030	.003
		Hearing Loss	1	26.311	.084	<.001
		Noise Group	1	42.863	.130	<.001
		Noise Level	2	179.507	**.556**	<.001
		Context	1	160.765	**.359**	<.001
		Noise Group × Noise Level	2	6.538	.044	.002
		Noise Group × Context	1	6.549	.022	.011
		Noise Group × Noise Level × Context	2	9.667	.063	<.001
		Error	287	.028		
	Recall	Hearing Loss	1	4.849	.033	.029
		Noise Group	1	7.443	.049	.007
		Noise Level	2	23.558	**.248**	<.001
		Error	143			

Note: Participant was covariate in all analyses. Values for partial eta squared effect size (η_p^2) were calculated applying Cohen's (1988) formula and are small ≥.01, medium ≥.059, and large ≥.138. Large effect sizes printed in bold.

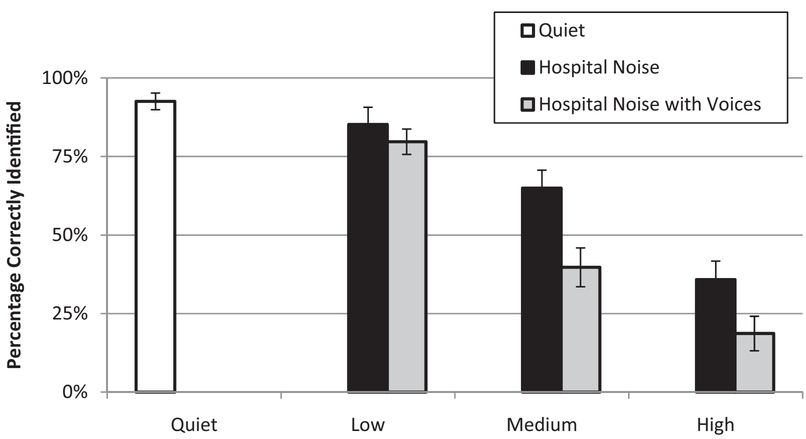

FIGURE 2. Percentage of key words identified by participants in quiet, hospital noise, and hospital noise with voices at low (59 dBA), medium* (64 dBA), and high (69 dBA) levels (graphed with 95% confidence intervals). *Medium levels equal the previously measured average decibel level at the Veterans Medical Center (Pope, 2010).

with context could not be measured.) A between-participant ANOVA was conducted with three factors (repeated testing, hospital noise group, and hearing loss) and one covariate (participant), and there were no significant effects. Average performance in recall for all participants across sentence context is shown in Figure 3.

White noise test condition. Results of a between-subject ANOVA conducted with four factors (context, noise level, hospital noise group, and hearing loss) and one covariate (participant) can be seen in Table 4. Both noise level and context had a significant effect on participants' performance in key word identification. The benefit of context decreased with increasing noise level. The ability to recall the key words was also significantly impaired by increasing noise level.

Hospital noise test conditions. Statistical analyses of key word identification, using a between-subject ANOVA with four factors (context, noise level, hospital noise group, and hearing loss) and one covariate (participant), revealed that each of the factors had a significant impact on accuracy. Noise level had the greatest effect on performance in key word identification for participants listening to low context sentences in hospital noise with voices. For the high context sentences, and for hospital noise without voices, the effects of noise level, while still large, did not have the same impact.

Calculation of a partial eta squared (η_{ρ}^{2}) metric to assess variance accounted for by the significant factors revealed that noise level accounted for the greatest amount of variance (56%), while context accounted for 36%. No other factors or interactions accounted for more than a small proportion of the variance. Performance in key word identification in the hospital noise and hospital noise with voices test conditions averaged across sentence context is shown in Figure 2. The lowest noise level resulted in average key word identification of 79% correct, while the highest noise level dramatically reduced accuracy to 19% correct when the listening condition was hospital noise with voices.

A between-participant ANOVA conducted on the recall data confirmed that noise level was again a significant factor, as was hospital noise group and hearing loss. As expected, recall of the five previous answers declined with increasing noise level. Noise level again accounted for the greatest amount of variance (25%), followed by noise group (5%) and hearing loss (3%). Performance in recall in the hospital noise and

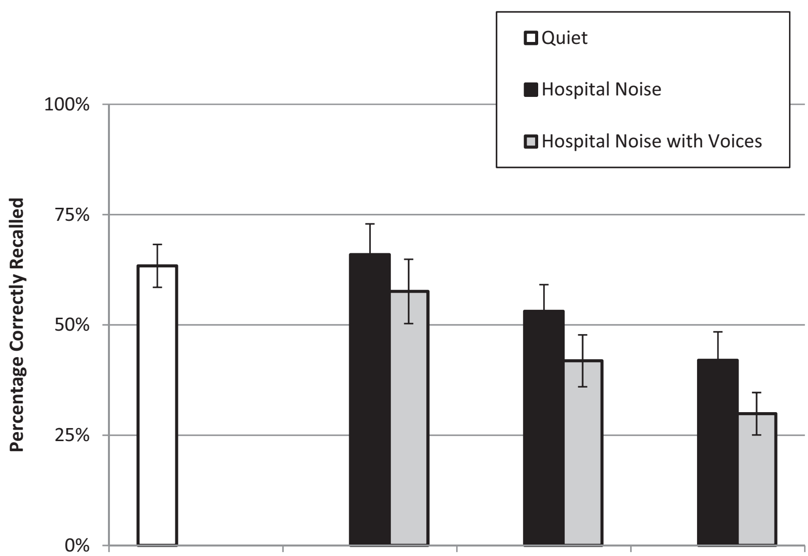

FIGURE 3. Percentage of key words recalled (even if identified incorrectly) by participants in quiet, hospital noise, and hospital noise with voices at low (59 dBA), medium* (64 dBA), and high (69 dBA) levels (graphed with 95% confidence intervals). *Medium levels equal the previously measured average decibel level at the Veterans Medical Center (Pope, 2010).

hospital noise with voices test conditions, averaged across sentence context, is shown in Figure 3. In hospital noise with voices, participants recalled 58% of their answers at the lowest noise level, 42% at the medium level, and 30% at the highest level.

Discussion

Medical/surgical inpatient participants were profoundly impaired in their ability to identify and recall key words when the test speech was masked by noise typical of medical/surgical hospital wards. Participants were significantly more impaired when the key word was in a low-context sentence, particularly when the noise included extraneous voices.

One of the intentions of our study was to determine whether lowering background noise levels would result in improved speech intelligibility, and our results do indicate that lower noise levels are associated with better performance in the speech-in-noise test. This evidence should support efforts to reduce hospital noise levels. We did not find consistent associations between participants' age, number of medications, or number of hospitalizations and their test performance, although hearing loss did play a role in their ability to complete testing.

To our knowledge, this is the first controlled study of speech intelligibility in hospital noise and the first study of hospitalized patients' ability to identify and recall speech in noise. These results are consistent with prior research related to intelligibility of speech in noise, as reviewed above, and should not be surprising to anyone who has spent time on a typical modern hospital ward.

Study results cannot be compared directly with other speech-in-noise tests because the hospital noise recordings used as masking were unique. Also, unlike actual clinical conditions, the speaker's voice in the R-SPIN test was presented at a constant level. It is likely that, in a clinical setting, the speaker would talk more loudly in a noisy environment, modifying the degree of difficulty in correctly identifying what is being said. It is worth noting again, however, that when people raise their voices, they lose clarity in their speech, increasing the difficulty of understanding for the listener (Kobayashi et al., 2007). In addition, every loud voice increases the overall environmental noise level.

The patient participants were on average both younger and healthier than the majority of the medical/surgical patients hospitalized during the study. It cannot be assumed that sicker inpatients would have performed less well than these study participants, but neither can it realistically be believed that they would have performed better. Older inpatients might be expected to perform less well, as there is extensive research on how reduced cognition with aging translates into increased effort to understand speech in noise. When the noise includes voices, the task of distinguishing speech requires even greater listening effort (Folmer, McMillan, Austin, & Henry, 2011; Hallgren et al., 2001, 2005; Larsby, Hallgren, Lyxell, & Arlinger, 2005; Pichora-Fuller, 2003; Pichora-Fuller & Souza, 2003). Pichora-Fuller (2003) and others cited above have concluded that the energy expended on identifying words in noise imposes sufficient cognitive burden on older listeners to reduce the energy available to remember the words, even a moment after they were identified.

A measure of the number of hospital admissions was included to determine whether there was a relationship between the familiarity with hospital noise (from the experience of multiple hospital admissions) and better performance in hospital noise. As stated above, no relationship was found. The number of hospitalizations was positively correlated with the number of medications prescribed on the day of testing ($r = .81$). Therefore, it is more likely that this variable was a proxy for how ill a Veteran was than for his or her familiarity with the setting.

Study participants were more likely to correctly identify high- versus low-context key words. This was expected (Pichora-Fuller et al., 1995) and has clinical relevance. Certain patient care tasks quickly become high-context in a hospital setting; for example, "it's time for your meds" becomes high-context when accompanied by a cup of pills, and this in turn may mitigate the negative effects of hospital noise on comprehension.

The findings indicate, however, that in a hospital environment, patients may be less successful in hearing, understanding, and remembering new information. Information communicated without a familiar frame of reference is, by definition, low-context and more likely to be misunderstood or missed altogether. This corresponds with results of studies of auditory processing in older adults (Pichora-Fuller, 2003; Pichora-Fuller & Souza, 2003). Discharge education, for example, frequently includes instructions about a new medication for which the patient has little context. The patient who quickly adapted to cues and comprehended contextualized communication about a familiar medication may have more difficulty understanding when no longer able to guess from a familiar frame of reference what is being said.

Unexpectedly, 17 of apparently fully eligible participants who had passed the audiology exam were not able to identify at least 80% of the key words in the speech intelligibility test in the first (quiet) testing condition, in the very quiet environment of a sound-attenuated booth where audiology exams are typically carried out. All but one of these 17 participants were categorized as hearing-impaired based on our study criteria and had more pronounced hearing loss than those who were able to complete the test. The hearing impairment inclusion/exclusion criteria were based on averages across the frequency spectrum. It is possible that we included participants who had significant hearing loss in particular frequencies important for hearing the speech presented in this testing, while having relatively good hearing in other frequency regions. While this may be true for some, it seems unlikely that this was true for all 17 participants. Voeks, Gallagher, Langer, and Drinka (1993) reported that 54 (27%) of the Veteran nursing home residents in their study who had normal audiograms in the speech-frequency range reported difficulty in hearing and understanding what was said. Half of those individuals had moderate to severe high-frequency hearing loss. The authors suggested that some of these patients may have experienced a central auditory processing disorder or a cognitive impairment. We did not screen explicitly for cognitive impairment and so it is possible that some of the 17 participants who were excluded had subtle cognitive deficits that we could not detect.

In addition to being older, these 17 participants had twice the number of prior hospitalizations as did the other 52. This may be explained somewhat by age, but it should be explored further, as there is evidence that individuals with significant hearing loss are less likely to seek healthcare, including recommended screenings (Folkins, Sadler, Ko, Branz, Marsh, & Bovee, 2005; Hoang, LaHousse, Nakaji, & Sadler, 2011; Sadler, Lee, Lim, & Fullerton, 2010). It may be possible that patients who do not hear and understand what is said to them during hospitalization have a higher risk of readmission. On the other hand, sicker patients may be at greater risk for not hearing, understanding, and remembering what they are told during hospitalization, regardless of hearing status. Regardless of the explanation, our findings suggest that many hospitalized patients may not easily understand what is said to them even in quiet conditions.

Strengths and Limitations

This study has several important limitations. Study participants were their own controls and were assigned to only one of the hospital noise conditions: some listened to hospital noise at three sound levels, and others listened to hospital noise with voices at the same three sound levels. The statistical analyses, however, revealed no significant differences between these groups of listeners when tested in either quiet or white noise, thus, our findings support the conclusion that the presence of voices in the hospital noise was the major factor that further reduced the participants' performance, rather than differences between participants.

A significant proportion of interpersonal communication is accomplished through body language, including lip-reading. Our study test did not include measures of body language, such as facial expression or hand gesticulations, that could have enhanced understanding. Thus our test was not a comprehensive measure of success in actual communication. The findings did, however, demonstrate the positive influence of high sentence context on correct key word identification in hospital noise, even without the benefit of body language.

Participants were mostly male, and all were US Veterans hospitalized in medical and surgical hospital wards at a Veterans hospital, so they are not representative of all hospitalized patients. In addition, this was a convenience sample, selected from those patients who had free time and were medically stable when study testing was available.

Insufficient sample size may have played a role in the lack of significance of association between participant characteristics and performance in the word identification and recall testing. There were indications that older participants were more likely to have hearing loss, and participants with hearing loss were more likely to have poorer performance during testing. However, noise level trumped all other factors, including participant characteristics, in reducing performance in both word identification and recall in all noise conditions. It is likely that communication for most if not all hospitalized patients is negatively affected by hospital noise.

Hospital acoustics are complex, and like all soundscapes are comprised of many components. Modern characterizations describe four domains of sound: (1) pressure—measured in decibels; (2) frequency spectrum—experienced as pitch; (3) duration; and (4) timbre—an umbrella term used to describe what makes one particular sound different from another when they may have the same pitch and loudness. Indoors, reverberation influences our experience of sound (Beutelmann & Brand, 2006). In this study, we controlled only for sound pressure (measured in decibels), and our results support the prevailing knowledge that increased sound pressure levels of masking noise diminish the ability to understand speech (Berglund et al., 1999; Duquesnoy, 1983; Hallgren et al., 2005; Kobayashi et al., 2007; Olsen, 1988; Shafiro & Gygi, 2007). We did not control for other components, such as reverberation, which also have been shown to influence speech intelligibility (Blomkvist, Eriksen, Theorell, Ulrich, & Rasmanis, 2005; Hagerman et al., 2005; MacLeod, Dunn, Busch-Vishniac, West, & Reedy, 2007), so we cannot be sure that noise level was the only acoustic factor that explained participants' test results.

Implications for Clinical Practice

The findings provide evidence that the acoustic environment where patient/provider communication takes place is an important factor in successful communication and that context is a factor that can mitigate the negative effect of noise on speech intelligibility. Older listeners have been shown to gain even more from context than do younger listeners (Pichora-Fuller et al., 1995). Thus, communication with patients in noisy settings like hospitals should be repetitive and enhanced with non-verbal strategies so that the information most important to communicate has become high-context by the time a patient is ready for discharge.

Beginning in January 2012, the Joint Commission on Accreditation of Healthcare Organizations required hospitals to have documented patient-centered communication standards (The Joint Commission, 2010). However, current guidelines do not include requirements associated with the acoustic environments where communication takes place. We suggest these guidelines should include measures to lower hospital noise levels in medical/surgical settings, particularly noise accompanied by voices, to improve speech intelligibility and thus the quality of care.

Recommendations for Future Research

Factors such as age and the number of medications or hospitalizations that could make it easier to identify patients who need enhanced communication interventions were not consistently associated with performance in the speech intelligibility and recall components of the study test. The findings do, however, suggest that development of a sensitive screening tool to determine difficulty in understanding speech in the hospital would be clinically useful for identifying those patients who may need enhanced communication interventions.

Our findings demonstrate that factors such as age, hearing loss, and cognitive function may be associated with speech intelligibility and recall in a hospitalized population. Studies are needed to test interventions to improve intelligibility as one aspect of communication with acutely ill patients.

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