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Divided Listening in Noise in a Mock-up of a Military Command Post

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ABSTRACT This study investigated divided listening in noise in a mock-up of a vehicular command post. The effects of background noise from the vehicle, unattended speech of coworkers on speech understanding, and a visual cue that directed attention to the message source were examined. Sixteen normal-hearing males participated in sixteen listening conditions, defined by combinations of the absence/presence of vehicle and speech babble noises, availability of a vision cue, and number of channels (2 or 3, diotic or dichotic, and loudspeakers) over which concurrent series of call sign, color, and number phrases were presented. All wore a communications headset with integrated hearing protection. A computer keyboard was used to encode phrases beginning with an assigned call sign. Subjects achieved close to 100% correct phrase identification when presented over the headset (with or without vehicle noise) or over the loudspeakers, without vehicle noise. In contrast, the percentage correct phrase identification was significantly less by 30 to 35% when presented over loudspeakers with vehicle noise. Vehicle noise combined with babble noise decreased the accuracy by an additional 12% for dichotic listening. Vision cues increased phrase identification accuracy by 7% for diotic listening. Outcomes could be explained by the at-ear energy spectra of the speech and noise.

INTRODUCTION

Military members, regardless of the environments in which they work, whether in ground-based, aviation, or naval operations, must cope, of necessity, with information overload in adverse circumstances.[1,2] For example, signal operators in vehicular command posts listen, transcribe, and respond to audio traffic from a number of radio networks associated with different levels of command in high-level background noise. Messages may be presented concurrently over the right and left earphones of several headsets, which are juggled by the operator, over loudspeakers mounted in their work space, and by the live voice of coworkers. Background noise may derive from a variety of sources, including vehicle engine systems, weapons and heavy artillery, and the unattended conversation of passengers and colleagues in close proximity. This scenario constitutes a problem of divided auditory attention, which is exacerbated by the masking effects of the background noise.

Studies of selective and divided attention have appeared in the scientific literature since the 1950s.[3–8] These showed that normal-hearing listeners can focus attention on a single talker among many (the "cocktail party effect") but will experience difficulty in understanding speech in competing message situations. Characteristics that differentiate the competitors, such as context, time of onset, apparent location, pitch, dialect, and intensity, will aid the intelligibility of targeted messages. These findings have been corroborated in more recent work, which show that performance is better when the target and interfering speech differ in intensity and the gender or pitch of the speakers or speech maskers[9,10] and their spatial location.[11–13] The effect of location may be tempered by the degree of separation of sources.[14] Prioritization of messages by visual, audiovisual, or tactile cueing also helps listeners to distinguish among sources and sounds.[4,10,15,16]

The intelligibility of targeted speech may be differentially affected depending on whether the competing sounds are energetic or informational maskers.[17,18] Energetic masking depends on the spectral overlap and thus the signal-to-noise ratio of the speech and masker (e.g., the noise of an engine). In informational masking, the listener has to disentangle elements of the two that sound similar (e.g., competing speech). This distinction is illustrated in a study by Brungart.[17] Subjects listened over a headset to target phrases in the presence of a single competing masker. The stimuli were diotic, i.e., the speech and maskers were mixed for presentation to both ears. Three speech maskers were investigated, speech, continuous noise, and speech-envelope modulated noise (i.e., continuous noise that has been shaped with the amplitude envelope of speech). The results showed that the greater the similarity between the targeted speech and the masker, the greater the degree of informational masking and the greater the performance decrement. Increasing the target-to-masker intensity ratio improved performance.

The present experiment investigated divided listening, i.e., listening and responding to more than one communications network (channel), in a stationary mock-up of the interior of the Canadian Forces Bison command, control, communications, and intelligence mobile command post (Bison C3I MCP), as shown in Figure 1. The detrimental effects on the accuracy of divided listening of energetic masking noise produced by the vehicle while driving along a highway and informational masking noise from speech babble modeling irrelevant conversation by other occupants in the vicinity of the operator's work station were studied. The possible benefits

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FIGURE 1. Interior view of the Bison command, control, communications, and intelligence mobile command post (Bison C3I MCP).

of providing visual cues that signify alternative channels over which targeted messages were presented was evaluated.

METHODS AND MATERIALS

Experimental Design

One group of sixteen normal-hearing (military or civilian) males, aged 21 to 40 years (mean of 30 years), served as the subjects. To control for the effect of language fluency on interpersonal communication, all subjects were Native English speakers. Studies have shown that nonfluent listeners have greater difficulty in understanding background noise.[19] Subjects were also screened based on self-report for a history of ear disease, excess wax buildup in the external ear, hearing loss and tinnitus, claustrophobia, and difficulty in maintaining attention over a 2-hour period, all those factors which could influence outcome. Those who passed these screening criteria underwent a hearing test conducted by a trained technician to ensure that pure-tone air conduction thresholds in each ear were no greater than 15 dB hearing level at seven frequencies between 0.5 and 8 kHz. This represents no more than a slight hearing loss.[20] Only those with an interaural difference not greater than 15 dB at each of the test frequencies were admissible to the study. The latter constraint was designed to minimize possible right/left ear differences in hearing that might create a bias in listening toward one ear. Subjects were also required to have normal or corrected normal vision (contact lenses) since they would have to read instructions on a computer screen without the use of spectacles. The temple bars of spectacles could interfere with the fit of the headset that subjects would have to wear.[21]

Each subject participated in sixteen listening conditions, consisting of combinations of two backgrounds (a digital recording of the noise heard within the Bison C3I MCP driving along a highway or quiet), absence or presence of recorded speech babble noise, absence or presence of visual cueing, and the number of alternative channels over which speech materials were presented (either loudspeakers and diotic headset or loudspeakers and dichotic headset). In diotic listening, the same stimulus is presented simultaneously to right and left ears. In dichotic listening, different stimuli are presented to right and left ears. Eight of the conditions were presented during the first of two 2½-hour sessions and the remainder during the second session held on a separate day no more than 2 weeks later. During a session, the absence or presence of the vehicle noise was held constant, the order counterbalanced across subjects. Diotic listening preceded dichotic listening, and in each of these headset conditions, absence of speech babble preceded presence of speech babble. In the two speech babble conditions, no visual cueing preceded visual cueing related to channel.

In each of the sixteen listening conditions, subjects were presented concurrently with a list of 60 phrases from each of the channels. The phrases were taken from the Coordinate Response Measure, a nonstandardized speech corpus for multitalker communications research, adapted by Bolia et al[22] to measure speech intelligibility in military environments. Each phrase in the corpus consisted of a call sign followed by a color–number combination, embedded in a carrier, e.g., “Baron go to Blue Five now”. In all, there are 256 phrases, made up of combinations of eight call signs (Charlie, Ringo, Laker, Hopper, Arrow, Tiger, Eagle, and Baron), four colors (Blue, Red, White, and Green) and eight numbers (1, 2, 3, 4, 5, 6, 7, and 8). Recorded lists spoken by four male and four female talkers are available for use. In the present study, since the effect of the number of channels (two vs. three) and the type of channel (headset vs. loudspeakers) were of primary interest, only the phrases spoken by one of the males was used to avoid confounding by voice quality. Each phrase was sampled at 40 kHz and digitally stored as a single file on the hard drive of the computer that was used in the study. The carrier words were deleted. These formed the database from which to draw the sets of phrases that were presented in the experiment. Sets differed across channels, conditions, and subjects.

The sets of phrases spoken over the various channels were not synchronous. The channels, whether two or three, were activated in turn in randomized sets of two or three respectively. The starting source was random. The subject was required to respond each time a phrase started with his designated call sign. He responded by pressing four coded keys in order on a standard laptop computer keyboard that indicated the channel (loudspeaker, diotic, right ear, or left ear), the call sign, the color, and the number heard. Each of the eight call signs was assigned to two of the sixteen subjects. This target call sign began 15 of the 60 phrases (25% probability of occurrence). Across the 15 trials, presentation of each of the 32 color–number pairings was random, with the restriction that each could occur only once. The remaining 224 call sign–color–number pairings were randomly chosen for presentation on the remaining 45 trials, with the restriction that none could occur more than once. The visual cue when present provided redundant information about the source. Each

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time the subject's call sign was presented, an image of the message source (right, left, or both earphones on the headset or the loudspeaker array) flashed on the computer monitor (see Fig. 2). The duration of each phrase was less than 3 seconds. Rate of presentation was approximately one phrase every 5 seconds. Thus, each listening condition took 10 or 15 minutes to complete, depending on whether presentations were from two or three channels. In order for a response to be counted, it had to be initiated during the interval between presentations. The duration of each of the two sessions, including the time for instructions (15 minutes) and rests between conditions (5 minutes), was approximately 2½ hours.

Bison C3I Mock-up

Subjects were tested individually while seated in front of a laptop computer in a mock-up of the Bison C3I MCP (see Fig. 3). The mock-up was situated in the Noise Simulation Facility of Defence Research and Development Canada—Toronto.[23] This facility is a semireverberant room of 10.55 × 6.10 × 3.05 m^3. An array of speakers comprising four low-frequency drivers (Bass Tech 7; ServoDrive, Glenview, Illinois), eight mid-frequency drivers (Gane G218; Equity Sound Investments, Bloomington, Indiana), and four high-frequency drivers (DMC 1152A; Electro-Voice, Burnsville, Minnesota) occupies the width of the shorter rear wall. These are powered by fourteen amplifiers (8 stereo model 4B and 6 mono model 7B; Bryston, Peterborough, Ontario). This array allows the acoustic simulation of a wide range of Canadian Forces operational noise environments, in terms of both levels, energy spectrum and time course, and is capable of producing noise levels in excess of 130 dB sound pressure level (SPL). The ambient noise in this facility is about 28 dB SPL.

FIGURE 2. Visual cues that appeared on the subjects' monitor for target phrases presented over the loudspeaker array or headset.

FIGURE 3. A subject seated in front of the laptop in the Bison C3I MCP mock-up.

Speech materials were presented at an at-ear level of 75 dB SPL over a headset (Racal Slimgard II RA108/1148; Esterline Technologies, Bellevue, Washington) or a ceiling suspended set of four loudspeakers (EVID 3.2t, Electro-Voice) surrounding the subject at a distance of about 1 m, just above ear level, at azimuth angles of 45° from the midline, front, and back. The Racal headset is currently used by personnel operating the Bison C3I MCP. The active noise reduction feature was not operational. The ambient noise level inside a Bison C3I MCP during highway driving has been measured to be 102 dBA.[24] A digital recording of this ambient was played over the loudspeaker array in the test room (outside the mock-up) at an at-ear level, beneath the headset, of 70 dBA. Recorded speech babble noise[25] was played within the mock-up over a powered monitor speaker (Model MS20S; Yamaha Canada Music, Toronto, Ontario), at an at-ear level of 75 dB SPL. This speaker was located directly behind the subject's head at a distance of approximately 1 m. The signal-to-noise ratios chosen, +5 dB in the case of the Bison background noise, and 0 dB in the case of the speech babble have previously been shown to result in speech understanding in the range of 60 to 80%.[26]

Procedure

Individuals who passed the screening criteria reviewed the protocol and signed a consent form that described the study before participating. At the start of each session, test subjects were fitted with the headset by a trained technician. Before the first condition, they had the opportunity to listen to brief samples of the vehicle and babble noise backgrounds. Test subjects also listened and responded to a series of four messages played over each of the possible channels (diotic, right ear, left ear, and loudspeakers). No feedback was given about the correctness of their responses. During each of the two experimental sessions, short rests were given after each of the eight listening conditions.

RESULTS

The dataset for each subject consisted of the following for each of the sixteen listening conditions, by channel: (1) the

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TABLE I. Percentage of Correct Identifications (Hits) of Call Sign, Channel, Color, and Number Combinations

		No Vehicle Noise		Vehicle Noise	
Headset	Channel	No Babble	Babble	No Babble	Babble
No Vision Cue					
Diotic	Loudspeakers	98.3 (3.0)[a]	95.4 (6.3)	66.3 (15.9)	60.4 (18.8)
	Binaural	98.7 (2.7)	98.7 (2.7)	99.2 (2.3)	97.5 (8.4)
Dichotic	Loudspeakers	98.7 (2.7)	95.0 (8.9)	67.9 (13.8)	54.6 (15.8)
	Left Ear	99.2 (2.3)	97.1 (4.8)	90.4 (20.7)	92.5 (14.4)
	Right Ear	99.2 (2.3)	97.9 (3.2)	96.7 (8.8)	99.2 (3.3)
Vision Cue					
Diotic	Loudspeakers	97.9 (3.2)	96.2 (8.4)	69.6 (11.7)	69.6 (15.6)
	Binaural	100.0 (0.0)	98.8 (3.6)	97.9 (4.0)	97.9 (4.0)
Dichotic	Loudspeakers	98.7 (2.7)	93.8 (9.6)	74.2 (15.6)	63.3 (15.2)
	Left Ear	98.7 (2.7)	95.8 (9.1)	90.8 (17.5)	96.7 (4.9)
	Right Ear	99.6 (1.7)	98.3 (3.0)	98.7 (2.7)	98.7 (2.7)

[a]Mean (SD), $N = 16$.

percentage of correct identifications of the channel, call sign, color, and number combinations for the 15 target phrases, (2) the percentage of correct identifications of each element taken separately for the 15 target phrases, (3) the percentage of false positives, i.e., responding to any of the 45 non-target phrases, and (4) the percentage of misses (not responding to targets).

Table I lists the percentage of correct identifications (hits) of all the elements of the phrase, i.e., call sign, channel, color, and number, as a function of the headset condition; the channel; the absence/presence of the vehicle and babble noises; and the vision cue. Separate repeated measures of analyses of variance (ANOVA)[27] were applied to the data obtained for the diotic and dichotic conditions because these involved different methods for presenting the messages (diotic headset or loudspeaker array vs. right or left earphones of the headset or loudspeaker array, respectively). When applied to the data for the diotic condition, the ANOVA showed statistically significant main effects of the vehicle noise ($p < 0.0001$), the babble noise ($p < 0.05$), the channel (diotic headset vs. loudspeakers; $p < 0.0001$) and significant interactions of the vehicle noise and channel ($p < 0.0001$) and the vehicle noise, visual cue, and channel ($p < 0.05$). The three-way interaction is displayed in Figure 4. As shown, subjects' mean percent correct was close to 100% when the phrases were presented over the headset in the presence or absence of vehicle noise and when the phrases were presented over the loudspeakers in the absence of the vehicle noise. Lower mean scores were observed when the phrases were presented over the loudspeakers in the vehicle noise, 70% with and 63% without visual cueing. The babble noise did not interact significantly with the other variables. Averaged across the absence/presence of the vehicle noise, visual cueing, and channel, the presence of the babble noise resulted in a decrease of 2%.

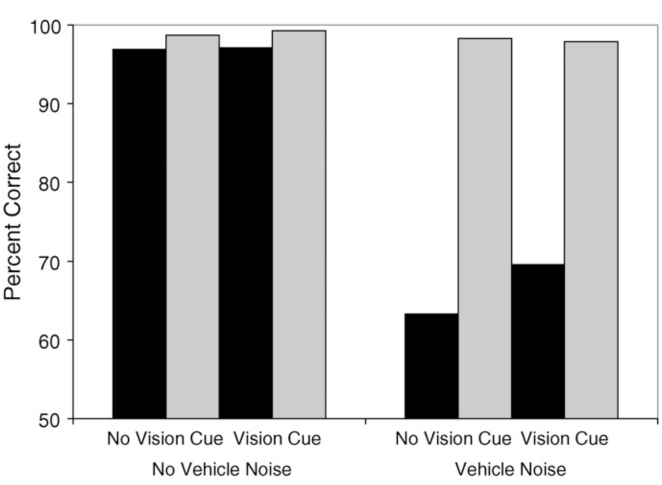

FIGURE 4. The percentage of correct responses (call sign, channel, color, and number correct) in the diotic listening condition plotted as a function of combinations of the absence/presence of the vehicle noise and the vision cue. The parameter in the graph is the source of the target phrases, loudspeaker (black bars), or diotic headset (gray bars).

A repeated measures ANOVA applied to the data for the dichotic condition showed statistically significant main effects of the vehicle noise ($p < 0.0001$), babble noise ($p < 0.002$), and channel ($p < 0.0001$) and significant interactions of the vehicle noise and channel ($p < 0.0001$), babble noise and channel ($p < 0.004$), and vehicle noise, babble noise, and channel ($p < 0.002$). The three-way interaction is shown in Figure 5. As in the diotic condition, the mean percent correct was close to 100% in the absence of the vehicle noise and greater than 90% when the phrases were presented over the right and left earphones of the headset in the vehicle noise. The lowest mean scores (71 and 59%) were observed when the phrases were presented over the loudspeakers with background vehicle noise and background babble and vehicle noises combined. In the dichotic listening condition, the vision cue did not provide a statistically significant benefit either as a main effect or in interaction with the other variables.

The results were also analyzed in terms of the percentages of correct channel, color, and number hits, taken separately, for each of the sixteen experimental conditions. Across conditions, the lowest percentage of channel hits observed was 88%

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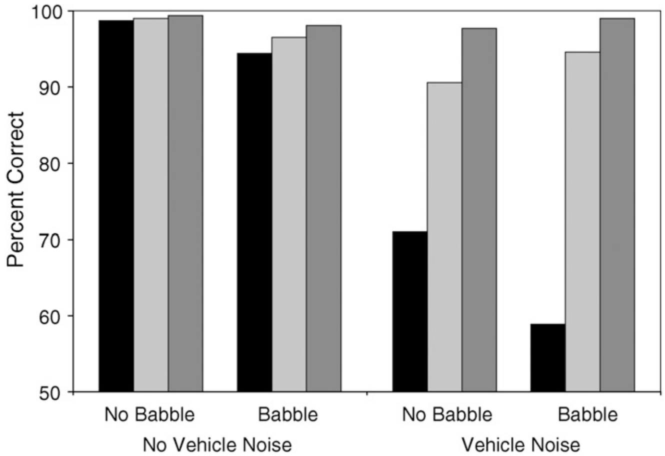

FIGURE 5. The percentage of correct responses (call sign, channel, color, and number correct) in the dichotic listening condition plotted as a function of combinations of the absence/presence of the vehicle and babble noises. The parameter in the graph is the source of the target phrases, loudspeaker (black bars), left headset (light gray bars), or right headset (dark gray bars).

(diotic condition, loudspeaker presentation, vehicle noise, and babble noise with no vision cue). The lowest percentage of number hits (83%) was observed in this same condition. These outcomes are in contrast to those for color hits, shown in Table II, where the lowest observed percentage correct was 58% (dichotic condition, loudspeaker presentation, vehicle and babble noises with no vision cue). The pattern of outcomes and scores were similar to those described above for four key accuracies. To determine the effect of the number of channels to which the subject had to respond (diotic headset vs. loudspeakers or right and left earphones of the headset vs. loudspeakers, respectively), the data obtained for the loudspeaker presentations (four keys correct) were compared for the diotic and dichotic headset conditions. An ANOVA applied to these data indicated that the number of channels was not a significant determinant of outcome.

Both misses and false positives were relatively infrequent. Misses, not responding on target trials, were less than 2% with a standard deviation of less than 3% except in four cases in which the presentations were over the loudspeakers in vehicle noise, either diotic or dichotic, with or without the babble noise and with no vision cue. The percentage of misses in these cases ranged from 6 to 10%. The percentage of false positives, responding on one of the 45 nontarget presentations, was consistently low at less than 0.8% under all sixteen listening conditions.

DISCUSSION

The present study was designed to assess the deleterious effects of energetic and informational masking noise,[17] separately and in combination, and the possible benefit of visual cueing, on the intelligibility of phrases delivered over two or three channels. The phrases presented over these channels did not overlap in time, but subjects had to continually monitor the channels to determine whether their assigned call sign had occurred. The call sign prompted the requirement to encode the channel over which the target message had been presented (its location), the call sign (confirming that subjects could select the correct key among the eight alternatives) and the two elements of the associated phrase (color and number). The speaker was the same in each case so that the only cue to the channel was location. Although the at-ear levels of the messages were the same, two of the channels fed directly into the right and left earphones of a communications headset, whereas the third channel was an external source (loudspeaker array).

The results showed that the subjects tested had no difficulty in understanding short phrases presented diotically or dichotically to the right and left earphones of the communications headset, with vehicle noise, babble noise, or both. Accuracy approached 100%. Phrase recognition was poorer when the phrases were presented over the loudspeaker array. Although the results, without the vehicle or babble noises, approached 100%, accuracy deteriorated significantly in the presence of vehicle noise (70%) and vehicle noise combined with babble noise (62%), averaged across diotic/dichotic

TABLE II. Percentage of Color Hits

Headset	Channel	No Vehicle Noise		Vehicle Noise	
		No Babble	Babble	No Babble	Babble
No Vision Cue					
Diotic	Loudspeakers	98.7 (2.7)[a]	96.2 (4.8)	69.2 (16.1)	66.2 (17.6)
	Binaural	99.6 (1.7)	99.2 (2.3)	99.2 (2.3)	97.5 (8.4)
Dichotic	Loudspeakers	98.7 (2.7)	95.4 (9.0)	70.8 (13.1)	58.3 (19.4)
	Left Ear	99.6 (1.7)	99.2 (2.3)	92.9 (18.8)	95.4 (9.3)
	Right Ear	99.6 (1.7)	98.7 (2.7)	97.5 (6.8)	100.0 (0.0)
Vision Cue					
Diotic	Loudspeakers	98.3 (3.0)	97.1 (5.4)	73.8 (10.2)	76.3 (13.3)
	Binaural	100.0 (0.0)	98.8 (3.6)	98.7 (2.7)	98.3 (3.8)
Dichotic	Loudspeakers	100.0 (0.0)	95.0 (9.3)	79.2 (13.3)	67.1 (15.9)
	Left Ear	99.2 (2.3)	97.1 (7.3)	92.5 (16.8)	97.9 (3.2)
	Right Ear	100.0 (0.0)	98.3 (3.0)	99.6 (1.7)	99.2 (2.3)

[a]Mean (SD), $N = 16$.

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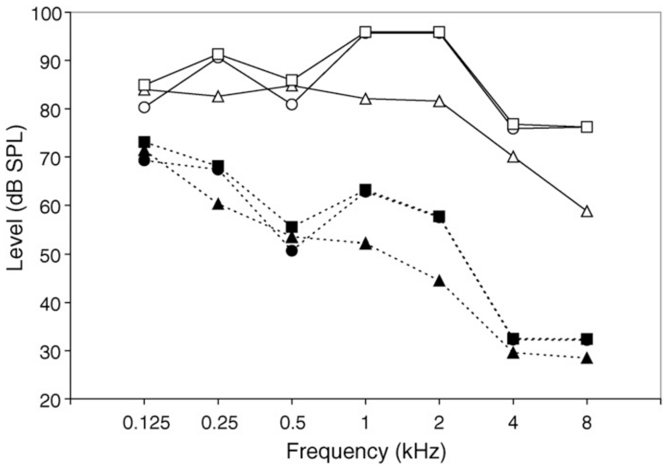

FIGURE 6. At-ear spectrum levels for the vehicle noise, babble noise, and vehicle and babble noises in combination, without (open symbols) and with (closed symbols) the Racal Slimgard II headset worn, as a function of the one-third octave band frequency. Parameters tested were vehicle noise (circle), babble noise (triangle), and vehicle and babble noises in combination (square).

headset presentation and the absence/presence of visual cueing. With the babble noise alone, subjects could achieve 95% correct phrase recognition. These results do not support Brungart's[17] finding that informational masking has a greater effect than energetic masking. The observed effect of the combination may have been due to an increase in the level of energetic masking. The results do support previous findings that cueing in another sensory modality is beneficial.[4,10,15,16] With the vehicle and babble noises in combination, subjects achieved 58% without visual cueing and 66% with visual cueing for the loudspeaker condition, averaged across diotic and dichotic listening.

Analysis of accuracy in correctly identifying elements of phrases presented over the loudspeakers in the combined noises showed that subjects had relatively little difficulty (80% or better) for all but the color. Mean scores observed for the color were similar to scores for 4-key accuracies, i.e., channel, call sign, color, and number, ranging from 58% (dichotic listening and no visual cue) to 76% (diotic listening and visual cue), suggesting that subjects' poor performance was mainly due to the category of the word presented. This is an unlikely explanation because in the case of the numbers, subjects had to choose from eight alternatives, whereas in the case of the colors, there were only four alternatives. This should have made the task much easier for the latter. The outcome could have been due to the serial position effect for recall of items in short-term memory.[28] Given a choice of order of recall, subjects will typically begin with the items near the end of the list (the recency effect) followed by those close to the beginning (the primacy effect). Middle items are recalled most poorly. In the present experiment, although recall was ordered, the same effect may apply.

A comparison of the at-ear energy spectra (right ear, 0.125–8 kHz) of the speech and noise helps to explain the outcomes. These measurements were made at the entrance to the ear canal of an acoustic test fixture,[29] using a ½-inch microphone (ER-11; Etymotic Research, Elk Grove Village, Illinois) connected to a spectrum analyzer (Type 2133; Brüel & Kjær Sound and Vibration Measurement, Nærum, Denmark). As shown in Figure 6, at both 1 and 2 kHz, the level of the vehicle noise was relatively higher than the babble noise by about 13 dB, regardless of whether the headset was worn. The differences between spectrum levels for the vehicle noise alone or in combination with the babble noise were negligible except at 500 Hz where the combined noise level was 5 dB higher. Table III shows the attenuation provided by the headset (the difference between protected and unprotected levels) for one-third octave bands centered at frequencies from 0.125 to 8 kHz for the vehicle noise, babble noise, and the two noises in combination, when compared with the manufacturer's specification. The headset provides 30 to 40 dB of attenuation from 0.5 to 8 kHz. Differences between the observed values, averaged across the three noise conditions, and the manufacturer's specification were less than 8 dB. Figure 7 shows the at-ear energy spectra (right ear) under the headset for the speech materials delivered over the communication channel of the headset and by the loudspeaker array, along with the energy spectrum of the vehicle noise in combination with the speech spectrum noise. For these measurements, the time gaps between the words and phrases were deleted. These data show that the level of the speech from the loudspeaker was well below that of the noise at all but 4 and 8 kHz. By comparison, the level of the speech presented over the headset exceeded the noise at 0.5, 2, and 4 kHz.

The energy spectra presented previously show clearly that one of the main reasons that signal operators experience difficulty during command and control operations in noisy

TABLE III. Observed Attenuation Compared With the Manufacturer's Specification for the Racal Slimgard II Headset

	One-third Octave Band Frequency (kHz)						
Noise Type	0.125	0.25	0.5	1	2	4	8
Vehicle	11.0[a]	23.2	30.2	32.9	38.2	43.6	44.0
Babble	12.6	22.3	31.3	29.9	37.1	40.5	30.3
Vehicle + Babble	11.8	23.2	30.4	32.7	38.2	44.3	43.8
Manufacturer	12.0	20.0	25.0	25.0	30.0	37.0	—

[a]dB SPL.

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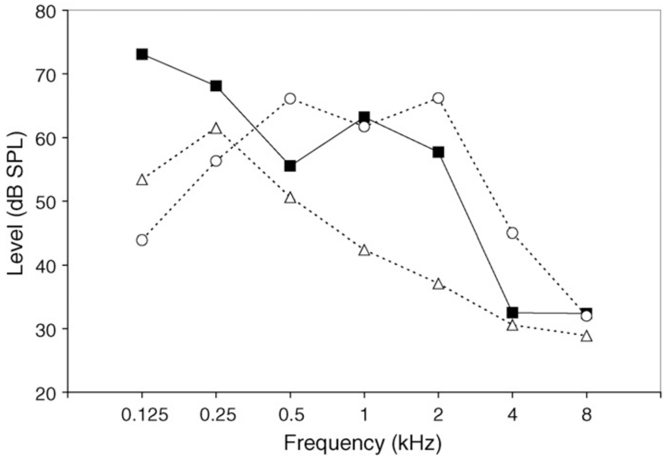

FIGURE 7. At-ear specrum levels under the Racal Slimgard II headset for the phrases presented either over the headset (unfilled circle) or loudspeakers (unfilled triangle) and the combination of vehicle and babble noises (filled black square).

environments is that they cannot hear and/or understand communications from sources that surround them, whether loudspeakers or live voice. In our previous focus group research, military members who worked in combat arms trades reported that they were obliged to lift the ear cups of their headsets to dialogue with coworkers, fully aware that they would compromise their hearing.[2] Another factor is auditory overload. We were unable to demonstrate the effect of increasing the number of communication channels from two to three in the present study, possibly because the messages from these did not overlap in time. However, we did find that providing a visual cue improved performance significantly in the diotic listening condition. In a recent study, Finomore et al[30] found that understanding phrases presented over six different channels was significantly better when these were delivered using text messaging compared with three-dimensional audio and radio communications. These results, taken with the present finding of improved performance with visual cueing, point to the need for further investigation of the possible benefits of using the visual modality to enhance audio communications.

In summary, the results of the study showed that subjects had no difficulty in understanding phrases presented over the headset or the loudspeakers in quiet or over the headset in the vehicle and/or babble noise backgrounds. Percent correct decreased significantly when the phrases were presented over the loudspeakers in the noise backgrounds. These outcomes could be explained by the at-ear energy spectra for the speech and noise. In the diotic listening condition, performance in noise over the loudspeaker was aided by a visual cue that indicated the source of targeted phrases.

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REFERENCES

1. Ericson MA, McKinley RL: The intelligibility of multiple talkers separated spatially in noise. In: Binaural and Spatial Hearing in Real and Virtual Environments, pp 701–24. Edited by Gilkey RH, Anderson TR. Mahwah, NJ, Erlbaum, 1997.
2. Abel SM: Barriers to hearing conservation programs in combat arms occupations. Aviat Space Environ Med 2008; 79: 591–8.
3. Hirsh IJ: The relation between localization and intelligibility. J Acoust Soc Am 1950; 22: 196–200.
4. Broadbent DE: Listening to one of two synchronous messages. J Exp Psychol 1952; 44: 51–5.
5. Cherry EC: Some experiments on the recognition of speech, with one and with two ears. J Acoust Soc Am 1953; 25: 975–9.
6. Egan JP, Carterette EC, Thwing EJ: Some factors affecting multichannel listening. J Acoust Soc Am 1954; 26: 774–82.
7. Webster JC, Thompson PO: Responding to both of two overlapping messages. J Acoust Soc Am 1954; 26: 396–402.
8. Webster JC, Sharpe L: Improvements in message reception resulting from "sequencing" competing messages. J Acoust Soc Am 1955; 27: 1194–8.
9. Brungart DS, Simpson BD, Ericson MA, Scott KR: Informational and energetic masking in the perception of multiple maskers. J Acoust Soc Am 2001; 110(5 Pt 1): 2527–38.
10. Drullman R, Bronkhorst AW: Speech perception and talker segregation: effects of level, pitch, and tactile support with multiple simultaneous talkers. J Acoust Soc Am 2004; 115: 3090–8.
11. Hawley ML, Litovsky RY, Colburn HS: Speech intelligibility and localization in a multi-source environment. J Acoust Soc Am 1999; 105: 3426–48.
12. Drullman R, Bronkhorst AW: Multichannel speech intelligibility and talker recognition using monaural, binaural, and three-dimensional auditory presentation. J Acoust Soc Am 2000; 107: 2224–5.
13. Arbogast TL, Mason CR, Kidd G Jr: The effect of spatial separation on informational and energetic masking of speech. J Acoust Soc Am 2002; 112: 2086–98.
14. Best V, Gallun FJ, Ihlefeld A, Shinn-Cunningham BG: The influence of spatial separation on divided listening. J Acoust Soc Am 2006; 120: 1506–16.
15. Rudmann DS, McCarley JS, Kramer AF: Biomodal displays improve speech comprehension in environments with multiple speakers. Hum Factors 2003; 45: 329–36.
16. Brungart DS, Kordik AJ, Simpson BD: Audio and visual cues in a two-talker divided attention speech-monitoring task. Hum Factors 2005; 47: 562–73.
17. Brungart DS: Informational and energetic masking effects in the perception of two simultaneous talkers. J Acoust Soc Am 2001; 109: 1101–9.
18. Wightman FL, Kistler DJ, O'Bryan A: Individual differences and age effects in a dichotic informational paradigm. J Acoust Soc Am 2010; 128: 270–9.
19. van Wijngaarden SJ, Steeneken HJM, Houtgast T: Quantifying the intelligibility of speech in noise for non-native talkers. J Acoust Soc Am 2002; 112: 3004–13.

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20. Yantis PA: Puretone air-conduction testing. In: Handbook of Clinical Audiology, Ed 3, pp 153–69. Edited by Katz J. Baltimore, MD, Williams & Wilkins, 1985.
21. Abel SM, Sass-Kortsak A, Kielar A: The effect on earmuff attenuation of other safety gear worn in combination. Noise Health 2002; 5: 1–13.
22. Bolia RS, Nelson WT, Ericson MA: A speech corpus for multitalker communications research. J Acoust Soc Am 2000; 107: 1065–6.
23. Nakashima A, Borland M: The Noise Simulation Facility at DRDC Toronto. Technical Report TR 2005-095. Toronto, Ontario, Canada, DRDC Toronto, October 2005.
24. Nakashima A, Borland M, Abel SM: Measurement of noise and vibration in Canadian Forces armoured vehicles. Ind Health 2007; 45: 318–27.
25. Kalikow DN, Stevens KN, Elliott LL: Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. J Acoust Soc Am 1977; 61: 1337–51.
26. Abel SM, Krever EM, Alberti PW: Auditory detection, discrimination and speech processing in ageing, noise-sensitive and hearing-impaired listeners. Scand Audiol 1990; 19: 43–54.
27. Daniel WW: Biostatistics: A Foundation for Analysis in the Health Sciences, Ed 3. New York, NY, Wiley, 1983.
28. Murdock BB Jr: The serial position effect of free recall. J Exp Psychol 1962; 64: 482–88.
29. Giguère C, Kunov H: An acoustic head simulator for hearing protector evaluation. II. Measurements in steady-state and impulse noise environments. J Acoust Soc Am 1989; 85: 1198–205.
30. Finomore V Jr, Popik D, Castle C, Dallman R: Effects of a network-centric multi-modal communication tool on a communication monitoring task. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, September 2010; 54: 2125–9. Available at http://pro.sagepub.com/; accessed November 17, 2011.

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