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Noise Hampers Children's Expressive Word Learning

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Abstract

Purpose—To determine the effects of noise and speech style on word learning in typically developing school-age children.

Method—Thirty-one participants ages 9;0 (years; months) to 10;11 attempted to learn 2 sets of 8 novel words and their referents. They heard all of the words 13 times each within meaningful narrative discourse. Signal-to-noise ratio (noise vs. quiet) and speech style (plain vs. clear) were manipulated such that half of the children heard the new words in broadband white noise and half heard them in quiet; within those conditions, each child heard one set of words produced in a plain speech style and another set in a clear speech style.

Results—Children who were trained in quiet learned to produce the word forms more accurately than those who were trained in noise. Clear speech resulted in more accurate word form productions than plain speech, whether the children had learned in noise or quiet. Learning from clear speech in noise and plain speech in quiet produced comparable results.

Conclusion—Noise limits expressive vocabulary growth in children, reducing the quality of word form representation in the lexicon. Clear speech input can aid expressive vocabulary growth in children, even in noisy environments.

Keywords

word learning; noise; clear speech

For the most part, children build their lexicons incidentally; they learn new words and their meanings as they encounter them in everyday environments (Best, Dockrell, & Braisby, 2006; Carey, 1978; Nagy & Herman, 1987). The incidental learner must parse the new word from the speech signal (Jusczyk & Houston, 1999) and, over time, come to represent fine-grained acoustic phonetic detail as well as coarser grained phonological generalizations in the long-term lexicon (Munson, Edwards, & Beckman, 2011). Moreover, the learner must build receptive and expressive links between the new word form and its meaning (Gupta, 2005). Learning from speech in everyday environments begins with—and therefore depends crucially on—perception of the acoustic signal. In this study, we examined children's word learning in response to more and less perceptible acoustic signals. Specifically, we asked whether noise disrupts word learning and whether use of a clear speech style ameliorates that disruption.

Noise

By the time they are 5 years old, many children spend most of their waking day in classroom environments that exceed recommended noise levels (American Speech-Language-Hearing Association [ASHA], 2005; Knecht, Nelson, Whitelaw, & Feth, 2002). In industrial societies, this noise is due primarily to heating, ventilation, and air-conditioning (HVAC) systems and nearby road traffic (Shield & Dockrell, 2003). Current national (American National Standards Institute [ANSI], 2002) and international (World Health Organization [WHO], 1999) guidelines recommend a maximum noise level in empty classrooms of 35 dBL_{Aeq} under the logic that a signal-to-noise (SNR) ratio of +15 dB is necessary for adequate communication and a typical teacher's voice level will be 55 dB_{SPL} at a distance of 1 m (Shield & Dockrell, 2003). However, in typical classrooms, ambient noise from HVAC systems alone ranges from 23 to 55 dB_A (Hodgson, Rempel, & Kennedy, 1999), and SNRs vary from +3 dB to +7 dB (Picard & Bradley, 2001).

Of course, in occupied classrooms, people contribute to the noise level as well. Children report chatter from other children as the most annoying sound source (Lundquist, Holmberg, & Landstrom, 2000) and the one that makes for the most adverse listening condition (Dockrell & Shield, 2004) in the classroom. Moreover, children's performance on verbal tasks suffers more in the presence of multitalker babble than in babble mixed with environmental noise (Dockrell & Shield, 2006).

Excessive noise has a detrimental effect on children's speech perception, attention, reading, spelling, behavior, and overall academic achievement (ANSI, 2002; ASHA, 2005; Berg, Blair, & Benson, 1996; Finitzo-Hieber & Tillman, 1978; Jamieson, Kranjc, Yu, & Hodgetts, 2004; Manlove, Frank, & Vernon-Feagans, 2001; McSparran, 1997). More specifically, children's performance on standardized tests of English is negatively correlated with classroom noise level (Shield & Dockrell, 2003).

The effect of noise on word learning per se is unknown. Word learning depends on the integrity of speech perception and the integrity of the memory trace, and noise interferes with both. Either the noise makes it difficult to recognize what is said, that is, it masks the stimulus, or, despite good recognition, the listener must expend so much effort distinguishing what is said that he or she has little cognitive energy left for processing and remembering the content.

In his seminal work, Rabbitt (1968) asked adult participants to listen to lists of digits that were presented in quiet and in background noise (modulated noise presented at 0 dB SNR). Participants were asked to transcribe half of the lists (i.e., write down the digits as they were hearing them) and to remember and recall the other half (i.e., reproduce the list at the conclusion of the presentation of the entire list). Participants transcribed the lists that were presented in quiet and in noise with equivalent accuracy, which led Rabbitt to conclude that speech perception was not affected by noise. However, recall was significantly poorer for the lists of digits that were presented in noise than for those presented in quiet. In a second experiment, recall of digits was poorer when the second half, rather than the first half, of the list to be remembered was presented in noise. Rabbitt concluded that noise interrupts rehearsal, encoding, or processing of spoken material even when perception of the items is not affected by the noise. This conclusion has been well supported over the years in a number of independent laboratories (Alain & Izenberg, 2003; Lavie, 1995; Murphy, Craik, Li, & Schneider, 2000; Pichora-Fuller, 2003; Pichora-Fuller, Schneider, & Daneman, 1995).

If listening to speech in noise taxes young adults' working memory systems, resulting in reduced abilities to remember spoken words, it stands to reason that listening to speech in noise may have an even greater impact on children's ability to learn and remember new

words. Young children approach the task of remembering words that are spoken in noise with at least two disadvantages as compared to young adults. First, children have poorer speech perception than young adults. They require higher SNRs to reach criterion on speech recognition-in-noise tasks than do teenagers and young adults (Blandy & Lutman, 2005; Choi, Lotto, Lewis, Hoover, & Stelmachowicz, 2008; Elliott, 1979; Fallon, Trehub, & Schneider, 2000; Nabelek & Robinson, 1982). Second, young children have more limited working memory capacity than young adults (Choi et al., 2008; Gathercole, 1998, 1999; Gathercole & Baddeley, 1989; Irwin-Chase & Burns, 2000).

Speech Style

Of course, perceptibility is not only a matter of noise, but also of the signal. When that signal is the spoken word, it is critical to recognize that most talkers naturally alter their speech style to facilitate communication with partners who are challenged by, for example, nonnative language or hearing impairment (Smiljani & Bradlow, 2008, 2009). The speech style they adopt has been termed *clear speech*. Speakers tend to hyperarticulate when producing clear speech, which results in highly distinct vowel categories (Bradlow, Kraus, & Hayes, 2003; Ferguson & Kewley-Port, 2002, 2007; Krause & Braida, 2004; Picheny, Durlach, & Braida, 1986). Clear speech also tends to be slower than plain speech (Bradlow et al., 2003; Bradlow, Torretta, & Pisoni, 1996; Picheny et al., 1986; Uchanski, Choi, Braida, Reed, & Durlach, 1996). Sentences read in clear speech have longer segments, fewer coarticulated segments, and more pauses—all of which contribute to longer durations (Smiljani & Bradlow, 2008). Regarding the perception of connected speech (sentences and texts), longer duration accounts for roughly half of the clear versus plain speech advantage (Liu & Zheng, 2006).

People speaking in noisy environments tend to modify their speech as well. These modifications, known as the Lombard effect, include increased intensity, pitch, and energy in higher frequencies (Cooke & Lu, 2010). In addition, common to both the Lombard effect and the clear speech style is an increase in segment duration (Pichora-Fuller, Goy, & van Lieshout, 2010). Nevertheless, these are distinct registers (Pichora-Fuller et al., 2010; Smiljani & Bradlow, 2009) with, for example, the hyperarticulation of the vowel space being more characteristic of clear speech.

Compared to plain speech, clear speech input improves speech perception (number of key words correctly recognized) under adverse communication conditions for adults with or without hearing impairment (Ferguson, 2004; Krause & Braida, 2002; Payton, Uchanski, & Braida, 1994; Picheny, Durlach, & Braida, 1985; Uchanski et al., 1996). For example, Payton et al. (1994) examined the effects of clearly spoken sentences in the presence of speech-shaped noise and/or reverberation in both normal hearing adults and adults with hearing impairment. Overall, they found a clear speech advantage of 21 percentage points across all listeners and all listening conditions. Payton et al. also discovered that the clear speech advantage increased as listening conditions worsened (SNR decreased and/or reverberation time increased). In fact, scores for the plainly produced stimuli dropped by 54% from the most advantageous listening condition to the most challenging condition, whereas scores for the clearly produced stimuli fell by only 36%. Even at relatively high SNRs, typically hearing adults demonstrated significant advantages for key word recognition of clearly produced speech versus plainly produced speech (20% in +9.5 SNR; 18% in +5.3 SNR).

To our knowledge, only one study of clear speech has involved young listeners. Bradlow et al. (2003) examined the effects of clear speech with a group of typically developing (TD) children and a group of children who had been diagnosed with learning disabilities (LD;

e.g., attention deficit disorder, learning disability, or both) and associated speech perception deficits. The participants listened to lists of sentences that were spoken in clear and plain speech styles in the presence of varying levels of background noise (−4 and −8 dB SNR). As expected, the children with LD had disproportionately more difficulty perceiving plain sentences in noise than did the TD children. However, clear speech enabled the children with LD to perform as well as their TD peers who listened to plain speech. In addition, like Payton et al. (1994), Bradlow et al. found that as listening conditions worsened (−8 dB SNR vs. −4 dB SNR), the clear speech advantage increased for both groups of children. Thus, Bradlow et al. concluded that everyday communication with children with or without LDs may be enhanced by adopting a clear speech style.

Word Learning

In the current study, we sought to extend research on noise and speech style to the domain of word learning. To mimic extended stages of word learning that occur in the real world, we trained new words incidentally via multiple exposures within narrative discourse contexts. To mimic problematic classroom noise, we introduced mild energetic masking (broadband white noise) during the training of half of the participants. Each child learned one set of words in response to clear speech input and another in response to plain speech input.

Word learning, in the most basic sense, involves committing to long-term memory the lexical form of the word (its phonemes, number of syllables, stress patterns), the semantics of the word (its referent), and a link between the two (Gupta, 2005). Commonly, we divide the word learning process into a fast mapping and extended mapping stage. *Fast mapping* refers to the phase of word learning in which a child stores some aspects of the word and referent in memory after only one or two exposures. The initial representation formed during the fast mapping phase may support comprehension, but it is often too weak to support production of the new word (Capone & McGregor, 2005; Carey, 1978; Dollaghan, 1985; Gershkoff-Stowe & Smith, 1997; Golinkoff, Hirsch-Pasek, Bailey, & Wenger, 1992; Horst & Samuelson, 2008; Mervis & Bertrand, 1994; Oetting, Rice, & Swank, 1995; Woodward, Markman, & Fitzsimmons, 1994). Production becomes more accurate with *extended mapping*, that is, after the learner has additional exposures to the word and its meaning over time that allow for re-encoding and enrichment of the memory trace. The mapping of a new word depends on the learner's speech perception (e.g., Werker & Yeung, 2005) and short-term memory abilities (e.g., Gathercole & Baddeley, 1993) and varies with the existing vocabulary knowledge of that learner (e.g., Storkel, 2009). The external environment matters too. Specifically, both fast and extended mapping depend critically on exposure to the spoken word. Therefore, we hypothesized that the perceptibility of the spoken word would influence word learning outcomes.

Given that noise makes it difficult to perceive new words and reduces the processing resources available for rehearsal and encoding the words in memory, we predicted that the mapping of word forms into long-term lexical memory would be poorer when those new words are presented in noise than in quiet. Because word recall requires the support of a deeper, more complete memory trace than word recognition, we predicted that a production probe would be more sensitive to the effects of noise than a comprehension probe.

Given that clear speech aids speech perception, and speech perception is the first step in word learning, we predicted that mapping word forms into long-term lexical memory would be better when those new words are presented in a clear speech than a plain speech register. We also predicted larger effects for production than comprehension. Furthermore, the effect of clear speech may be particularly pronounced in the presence of noise because that is precisely where more intelligible speech input is needed. Finally, because of potentially

important educational implications, we asked whether the effect of clear speech was great enough to ameliorate the learning impediment imposed by noise. To address this question, we compared performance under plain speech conditions in quiet to performance under clear speech conditions in noise.

METHOD

Participants

Thirty-one TD children were recruited by flyers and word of mouth from the greater DeKalb-Sycamore, IL area. The participants were monolingual, English-speaking children ages 9;1 (years; months) to 10;11. There were 16 girls and 15 boys. One participant was Native American, one was Asian, one was African American, and the rest were Caucasian. Per parent report, all of the children were enrolled at age-appropriate grade level in school, and none had current or previous speech, language, visual, or learning difficulties. The study was approved by the university's Institutional Review Board.

Once enrolled in the study, all participants underwent an audiological evaluation by a licensed audiologist. Audiometric thresholds were obtained at 500, 1000, 2000, 4000, and 8000 Hz; immittance measures were also obtained. Exclusionary criteria were hearing thresholds >20 dB_{HL} at any frequency or evidence of middle ear pathology in both ears. No participants were excluded from the study based on these criteria.

Participants completed three standardized tests: The Non-Word Repetition subtest of the NEPSY (Korkman, Kirk, & Kemp, 2007); the Peabody Picture Vocabulary Test—Fourth Edition (PPVT-IV; Dunn & Dunn, 2007); and Lists 7, 8, 9, and 10 of the Revised BKB Standard Sentence Test (Bench & Bamford, 1979).

The NEPSY was standardized on a sample of 1,000 children that was representative of the demographics of the United States (Korkman et al., 2007). The convergent evidence of validity of the language domain of the NEPSY (which includes the Non-Word Repetition subtest) is demonstrated via a positive correlation to verbal IQ as measured by the Wechsler Preschool and Primary Scales of Intelligence—Revised (Wechsler, 1989; $r = .60$) and the language domain of group-administered achievement tests ($r = .49$). Test-retest reliability of the repetition of nonsense words of the NEPSY averages .80 for children ages 5 to 12 years.

The PPVT-IV was standardized on 3,540 children and adults representative of the United States (Dunn & Dunn, 2007). Convergent evidence of validity is provided via a correlation of .79 between the PPVT-IV and the lexical/semantic composite of the Comprehensive Assessment of Spoken Language (Carrow-Woolfolk, 1999). Test-retest reliability is .93.

The BKB sentences were created using vocabulary and sentence structures common to 240 children with hearing loss to ensure that they were child friendly and low in linguistic load. Therefore, the validity of the BKB as a measure of speech perception is attested to by its *lack* of correlation with measures of linguistic ability (Bench, Kowal, & Bamford, 1979). Its validity as a measure of perception of connected speech is attested to by higher performance-intensity functions for the BKB sentences than for words from the BKB sentences presented in isolation (Kirk, Diefendorf, Pisoni, & Robbins, 1997). Finally, the test-retest reliability is indicated by an average difference in speech recognition threshold between test and retest 3 months later of ± 1.29 dB, with an *SD* of 1.75 dB (Bamford & Wilson, 1979).

The primary rationale for administering these tests was to determine whether the children assigned to learn in quiet or in noise brought similar short-term memory (NEPSY scores),

extant vocabulary (PPVT–IV scores), and speech perception (BKB scores) to the task—all of which are known to influence word learning. A second purpose of the BKB, in particular, was to ensure the validity of our experimental findings regarding the effect of clear speech on word learning by demonstrating that we could replicate the effect of clear speech on speech perception as reported in Bradlow et al. (2003).

Children were assigned to either the noise or quiet experimental group based on their test scores and age. Independent-samples *t* tests revealed that the two groups, noise versus quiet, were well-matched for scores on the NEPSY, $t(29) = .03$, $p = .97$; PPVT, $t(29) = .40$, $p = .69$; and BKB-8SNR plain, $t(29) = -.52$, $p = .61$ (Groups are considered well-matched if *p* values are $>.5$ [Mervis & Klein-Tasman, 2004]). Although the groups did not differ significantly on chronological age, $t(29) = -1.47$, $p = .15$, or BKB-8SNR clear, $t(29) = -1.20$, $p = .24$, the noise group tended to be younger and less able than the quiet group to respond to clear speech in noise. Therefore, chronological age in months and BKB-8SNR clear scores were treated as covariates when group comparisons were made.

Materials

Training narratives—Participants were taught eight novel words paired with eight novel object referents under each speech condition. Words and referents were presented to the participants in the form of computer-generated training narratives. Word-referent pairs were counterbalanced across conditions and participants. For the noise group, stimuli were presented in the presence of speech-shaped noise at +8 SNR under the rationale that this is a realistic, yet conservative, estimate of the SNR in typical classrooms (Picard & Bradley, 2001).

During the training narratives, 16 novel referents from McGregor et al. (2012) were presented as line drawings. Half were animate referents created by combining two known animates (e.g., half pig and half bird); half were inanimate referents created by combining two known artifacts (e.g., half canoe and half banana). The corresponding 16 novel consonant-vowel-consonant (CVC) object labels were randomly chosen from the Gupta et al. (2004) corpus of single-syllable (CVC) nonwords. In each narrative, participants were exposed to the stimuli three times each. For the first and third exposures, stimuli were presented in a serial list (e.g., *I see the _____, the _____, the _____* etc.). For the second exposure, the stimuli were presented in sentence-final position (see Appendix A).

All of the auditory stimuli (i.e., participant instructions, narratives, target words) were recorded in a double-walled sound-treated booth. A female talker read the stimuli into a Shure SM81 microphone that fed into an iMac desktop computer. Recording was done on a single channel at a sampling rate of 16 kHz using Sound Studio 3 audio recording software. Throughout the recording session, the input level was monitored to prevent exceeding the maximum level of the dynamic range of the recording system. The audio files were saved in a digital format (.wav) for later manipulation via Praat speech analysis software (Boersma & Weenink, 2009). The overall intensity of the files was equalized with custom software created in MATLAB (2008) to 65 dB SPL. Broadband white noise was then digitally added to the files used for training the noise group. We used custom software in MATLAB to ensure that the length of the noise and narrative stimuli were equivalent, to combine the noise and narrative files, and to appropriately scale the noise to the experimental SNR (+8 SNR).

Each training narrative was recorded by the same female speaker in both clear and plain speech. For clear speech, the speaker was asked to read the narratives while imagining that the listener had a hearing loss or was from a different language community. For plain

speech, the speaker was asked to read at a normal rate as if talking to a listener who was highly familiar.

We took two measures of duration to ensure that the clear and plain speech registers were acoustically distinct. Although longer duration is not the only relevant acoustic characteristic of clear speech, in connected speech such as that used here, it is a powerful predictor, accounting for roughly half of the clear versus plain speech advantage (Liu & Zeng, 2006). First, we measured duration of the narratives and found that those produced with clear speech were statistically longer than those produced with plain speech (Clear $M = 232.26$ s, $SD = 37.35$ s; Plain $M = 196.44$ s, $SD = 31.11$ s), $t(5) = 13.037$, $p < .001$, $d = 1.14$. Second, we measured the duration of the target words within the narratives and found that those produced within the clear narratives were statistically longer than the same target words produced within the plain narratives (Clear $M = .584$ s, $SD = .112$ s; Plain $M = .477$ s, $SD = .119$ s), $t(143) = 20.308$, $p < .001$, $d = .93$. Therefore, both the overall narrative and the word-learning targets within the narrative were longer in the clear speech register.

Comprehension probe—A four-alternative, forced-choice task was designed to test learning of the word referents. For this task, the novel referents that had been trained were presented one each in an array of three other pictured referents—two exposed novel referents (they were seen but not labeled during the narrative; one semantically related item and one item from the other semantic category) and one never-before-seen novel item that was semantically related to the target. The two semantically related foils differed from one another in that one was a close semantic foil (i.e., it shared a specific semantic feature with the target other than animacy or inanimacy) and the other was a far semantic foil (it only shared the feature of animacy or inanimacy with the target). Appendix B provides a sample comprehensive probe array.

Procedure

The experiment consisted of four sessions lasting from 15 to 20 min. There was at least 1 day and no more than 2 days between Sessions 1 and 2 (training of the first word set) and between Sessions 3 and 4 (training of the second word set). There was no significant difference in length of time between sessions for the two experimental groups (Sessions 1 to 2, $p = .699$; Sessions 3 to 4, $p = .297$). During all sessions, participants were seated in front of the same Dell Latitude 830 laptop computer to view visually presented stimuli and listen to auditory stimuli via Logitech Laptop computer speakers. All verbal instructions were presented via E-prime software (Schneider, Eschman, & Zuccolotto, 2002a, 2002b) in quiet using plain speech at 65 dB SPL.

Two consecutive sessions were devoted to each condition (clear and plain speech). The order of clear and plain conditions was counterbalanced across participants. In each condition, the procedures were identical; the only difference was whether the target words and the surrounding narrative frames were presented in clear speech or plain speech.

A flow chart illustrating the order of the steps in the experiment is provided in Figure 1. On Day 1, each participant viewed and heard a training narrative in which all eight of the novel items were displayed and labeled three times. Following the narrative, a comprehension probe was conducted. During the comprehension probe, participants saw four items on the computer screen and heard, "Click on the XXX," with XXX being the target novel item label for that trial. Children used the computer mouse to click on the correct target; accuracy was recorded electronically within the E-prime software. Thus, accuracy of the forced-choice decision served as the dependent variable. Immediately following the first comprehension probe, each participant viewed and heard a second, different narrative in which the same eight test items (and exposed foils) were displayed and simultaneously

labeled three times. Another comprehension probe was then conducted that was identical to the first except that the order of the items differed. At the end of the first session, each participant had eight exposures to each of the eight target words, three in each of two narrative contexts and once in each of the comprehension probes.

One to 2 days later, each participant returned to complete the extended word learning phase of his or her first condition. A comprehension probe identical to the one described in the previous paragraph, but with items presented in a different order, was conducted to measure retention of the test items. Following this, a third and different narrative in which the eight test items were displayed and simultaneously labeled three times was seen and heard by each participant. This was followed by a final comprehension probe that was identical to the others. Finally, each of the items appeared one at a time on the computer screen, and the child was asked to produce its name. The number of words recalled and the number of phonemes correct per word were recorded manually by the experimenter, with responses also being captured on a digital recording device (H4n Handy Recorder, Zoom Corporation) for verification. Thus, number of words recalled and their accuracy served as dependent variables. Recall was defined as any CVC production in response to the pictured stimuli. Accuracy was calculated as the number of phonemes that were produced correctly divided by the number of words that were recalled. By the time the participant was asked to produce these new words, he or she had been exposed to them 13 times, three times in each of three stories and once in each of four comprehension probes.

On the final 2 days of the study, each participant repeated the procedure described above with a new set of eight words and a different input condition (clear or plain speech).

Reliability—A second rater independently coded the production responses for a random sample of six children (three each from the two experimental groups). Point-by-point phoneme agreement for the production probes was 96.5% overall (278 phonemes agreed on out of 288 total). There was no difference in agreement between groups (quiet 96.5%, noise 96.5%) or conditions (clear 96.5%, plain 96.5%). Differences were resolved by discussion while listening to the recordings.

RESULTS

BKB scores

Because studies of clear speech effects on listeners who are children are so rare, we took the initial step of replicating Bradlow et al. (2003). If we did not get clear speech advantages in word learning, a replication of clear speech effects on speech perception would be valuable in shaping an interpretation. Participants performed at or near ceiling when the lists were presented in quiet (Clear, $M = 50$, $SD = 0$; Plain, $M = 49.90$, $SD = .30$). Given an SNR of -8 dB, participants repeated significantly more key words under conditions of clear speech ($M = 19.19$, $SD = 5.17$) than under conditions of plain speech ($M = 7.42$, $SD = 3.88$); $t(30) = 12.28$, $p < .001$, $d = 2.20$. Therefore, the child participants in the current study demonstrated enhanced speech perception in noise when listening to clear speech as compared to plain speech. Given this replication of Bradlow et al. (2003), we went on to examine the effect of clear speech on the children's word learning.

Comprehension probe

Participants performed at or near ceiling for accuracy on the first and all subsequent comprehension probes with number of accurate responses, out of 8 possible, ranging from 7.85 to 7.89 across groups (noise or quiet) and conditions (plain or clear) (Table 1). That is, after just three exposures to the word and its referent in a meaningful narrative context (upon

which the first comprehension probe was administered), the participants had encoded enough information to choose the correct referent out of an array of four upon hearing the name of the referent. In the rare instances when errors were made (20 errors in total out of 1,792 attempts), participants always selected the close semantic foil (the item sharing the most semantic features with the target) from the array, suggesting some memory for aspects of the referent even in cases of error. It appears that mapping a word form well enough to recognize it when it is spoken and link it to its referent is not compromised by mild noise, plain speech, or their combination.

Production probe

We conducted two 2×2 mixed analyses of covariance (ANCOVAs) to evaluate the number of words recalled and the accuracy of their production. In both cases, the between-subjects factor was SNR group (quiet vs. noise), the within-subjects factor was speech condition (clear speech vs. plain speech), and participants' age and BKB-in-noise scores (clear speech condition) were covariates. The first dependent variable was the number of new words recalled. There was a marginal effect of group, $F(1, 27) = 3.87, p = .06, \eta_p^2 = 0.13$, such that the children who learned in noise recalled *more* names ($M = 4.38, SD = 1.52$) than those who learned in quiet ($M = 3.37, SD = 1.55$). There was no effect of speech condition (Clear $M = 3.82, SD = 2.16$; Plain $M = 3.92, SD = 2.06$), $F(1, 27) < 1, p = .38$, nor any Group $\times$ Condition interaction, (Clear noise: $M = 4.38, SD = 2.28$; Clear quiet: $M = 3.27, SD = 1.94$; Plain noise: $M = 4.38, SD = 2.16$; Plain quiet: $M = 3.47, SD = 1.92$), $F(1, 27) < 1, p = .99$. Neither covariate was significant, BKB: $F(1, 27) < 1, p = .37$ and age: $F(1, 27) = 3.02, p = .09$.

The second dependent variable captured the accuracy of the productions. The result is captured in Figure 2. There was a significant main effect for group, $F(1, 27) = 5.30, p = .03, \eta_p^2 = 0.16$, with the participants in the quiet group producing more correct phonemes per word ($M = 2.70, SD = .46$) than those in the noise group ($M = 2.32, SD = .48$). There was also a marginal effect for speech condition, $F(1, 27) = 4.0, p = .056, \eta_p^2 = 0.13$, with the clear speech condition eliciting more correct phonemes per word than the plain speech condition (Clear: $M = 2.62, SD = .59$; Plain: $M = 2.39, SD = .62$). There was no interaction between the two factors (Clear noise: $M = 2.43, SD = .71$; Clear quiet: $M = 2.81, SD = .35$; Plain noise: $M = 2.20, SD = .66$; Plain quiet: $M = 2.58, SD = .52$), $F(1, 27) < 1, p = .51$, and neither covariate was significant, BKB: $F(1, 27) < 1, p = .78$ and age: $F(1, 27) < 1, p = .50$.

Finally, we compared the accuracy of the productions of the participants in the noise group and clear speech condition ($M = 2.44, SD = .71$) to that of the participants in the quiet group and plain speech condition ($M = 2.58, SD = .52$) to determine whether clear speech helps to compensate for the detrimental effects of noise. The means were not significantly different, $t = .66, (29), p = .52, d = .24$. Non-overlap of these two data sets fell between 14.7% and 21.3%.

DISCUSSION

The overarching goal of this study was to determine how the perceptibility of the acoustic signal affects word learning. A mild level of background noise did not diminish comprehension of words, as tapped by a four-alternative forced-choice recognition probe, or the number of word forms recalled, as tapped by a referent name production probe. However, the accuracy with which words were produced was lower when the words had been learned in noise than in quiet. In both quiet and noisy training conditions, the accuracy of word recall was (marginally) stronger when training scripts were presented in a clear speech register than in a plain speech register. Clear speech ameliorated the effect of noise

in that learning in response to clear speech in noise and learning in response to plain speech in quiet were comparable.

We view this laboratory-based study as conservative in that it likely underestimates the size of the effects of noise and speech style on listening and learning in naturalistic environments. For the noise manipulation in particular, consider the following six points. First, because the comprehension probe was administered four times before the production probe, the children assigned to the noise group had the benefit of hearing four productions of each word form in quiet. Second, the level of noise we selected, +8 dB SNR, is mild. Measurements in actual classroom environments ranged from +3dB to +7 dB, with classrooms of younger students having poorer SNRs than classrooms of older students (Picard & Bradley, 2001). Third, the type of noise we used, broadband white noise, was likely not as disruptive as actual speech would be. Multitalker babble is a powerful impediment to speech perception (Simpson & Cooke, 2005) and verbal processing (Dockrell & Shield, 2006). Fourth, we limited the source of acoustical interference to noise, but classroom environments are also characterized by high levels of reverberation (ANSI, 2002; ASHA, 2005; Berg et al., 1996; Knecht et al., 2002; Picard & Bradley, 2001; Yacullo & Hawkins, 1987). The effect of noise plus reverberation on schoolchildren's word discrimination is known to be more deleterious than the effect of either alone (Finitzo-Hieber & Tillman, 1978). Fifth, we introduced noise during a short-term learning activity. Although this acute exposure affected the children's performance, the effect of chronic noise exposure would be expected to be greater (Maxwell & Evans, 2000; Stansfeld et al., 2005). Finally, all of our participants had normal language learning mechanisms. For children with special educational needs, verbal processing is more adversely affected by noise than for other children (Dockrell & Shield, 2006). Therefore, given more diverse learners under more realistic classroom conditions, the impact of noise would likely prove even more detrimental to word learning than under the current experimental conditions.

Which Aspects of Word Learning Are Most Vulnerable to Noise?

As predicted, comprehension of word forms was less affected by noise than production. In fact, there were no effects of noise or speech style on the accuracy of comprehension performance. In this study, comprehension was tested in a recognition format via a forced-choice array. This is an extremely common method in studies of word learning, and the typical finding is that even very young children can select the correct referent from an array upon hearing its name after minimal exposure (Capone & McGregor, 2005; Carey, 1978; Dollaghan, 1985; Gershkoff-Stowe & Smith, 1997; Golinkoff et al., 1992; Horst & Samuelson, 2008; Mervis & Bertrand, 1994; Oetting et al., 1995; Woodward et al., 1994). In the current study, this high level of performance was not merely a matter of familiarity, as two of the three foils in each array had also been presented (but not named) in the training script. Moreover, in the very few cases of error, children picked a foil that was semantically similar (in animacy and certain shared physical features) to the target, suggesting that they had at least mapped some relevant information about the referent.

Word form production was tested after 13 exposures by presenting the visual referents and asking for their names. Overall, this was a difficult task. Out of eight words trained in each set, participants typically recalled only three or four. However, this finding is highly typical. In McGregor, Sheng, and Ball (2007), participants of similar ages attempted to learn 20 new words and referents when given either 16 or 32 exposures to the words over the course of 2 weeks. Afterward, when asked to name the referents, the participants with lower exposure recalled approximately six of the 20 word forms; those with higher exposure recalled about eight. Learning word forms well enough to recall them, especially in multiples, is a challenging task even for school-age children with intact learning abilities.

Nevertheless, the number of word forms that the children in the current study recalled was not adversely affected by noise. In fact, the children who learned in noise recalled (marginally) more word forms than those who learned in quiet. It was the *quality*, rather than the *quantity*, of word form representation that was hampered by noise. All words trained in the current study contained three phonemes (CVC). On average, children who learned these forms in noise accurately produced 2.3 of these per word, but those who learned in quiet accurately produced 2.7. This implies that the representations encoded in noise were less detailed or more fragile and therefore more vulnerable to errors.

Perhaps noise masked the energy in the target words, making them difficult to perceive. An alternative, more top-down, explanation is that noise interfered with memory encoding because extra effort must be devoted to perception (McCoy et al., 2005) or because attention must be devoted to segregation of the noise from the target (Heinrich, Schneider, & Craik, 2008). In either case, a less than ideal signal (as represented by either plain speech or a low SNR) will potentially drain resources, minimize the depth and elaborateness of encoding, and limit the accuracy of recall attempts. Although we cannot select from these explanations on the basis of the current data set, it is useful to recall that noise can disrupt memory even when adequate perception can be proved (Rabbitt, 1968).

What Are the Implications for Educators?

It has been established that background noise detrimentally affects various aspects of school-age children's academic achievement (ANSI, 2002; ASHA, 2005; Berg et al., 1996; Finitzo-Hieber & Tillman, 1978; Jamieson et al., 2004; Manlove et al., 2001; McSporran, 1997). To this, we add that expressive word learning is negatively affected by the presence of energetic masking noise. As this sort of noise resembles that produced by HVAC systems and road traffic, school administrators should consider their compliance with recommended noise level maximums. Steps can be taken to reduce noise levels, including covering hard surfaces (ceilings, walls, or floors) with softer—and thereby sound-absorbing—materials such as acoustic ceiling tiles, fabrics and carpets; glazing or replacing windows; and maintaining or replacing HVAC systems for maximum efficiency (Ehrlich & Gurovich, 2004).

We also demonstrated that the use of clear speech can help children to overcome some of the detriments of learning in noise. The accuracy of word form attempt following learning from clear speech input in a noisy environment was not different from that following learning from plain speech input in a quiet environment. For the purposes of experimental control, we instructed our speaker to use clear speech, and we recorded her in a quiet, sound-treated booth. We then mixed this recorded signal with noise for children who were assigned to the noise group. However, in true noisy environments, the Lombard effect will engage, that is, speakers will tend to modify their speech automatically to improve their intelligibility. The implication is that many teachers likely employ slower (and louder) speech in noisy classrooms, which may help children to learn. Nevertheless, clear speech involves additional changes, especially in the hyperarticulation of the vowel space, and these changes are associated with improvements in intelligibility (Pichora-Fuller et al., 2010; Smiljani & Bradlow, 2009).

Clear speech is not difficult to teach. In fact, in the laboratory, it is typically elicited by asking people to imagine that they are speaking to someone who is hearing impaired, to articulate clearly, and to avoid slurring (Pichora-Fuller et al., 2010). That said, there are individual differences, with some people being better at clear speech than others (Smiljani & Bradlow, 2009). Better users increase their vowel space to a greater extent over their plain speech register as compared to poorer users (Ferguson & Kewley-Port, 2007). Therefore,

there may well be advantages in instructing teachers, especially those who must function in noisy environments, in the use of a clear speech register.

It must be stressed that these implications represent hypotheses about steps that might lead to improved word learning in classrooms. Evidence in support of these hypotheses requires experimentation in actual classroom environments.

Conclusion

Noise hampers expressive word learning for two potential reasons: Noise makes it difficult to perceive the new words, and difficult perception drains cognitive resources away from the establishment of a robust memory trace. Either or both may interfere with the quality of the representation of the word form in the lexicon and the accuracy of its production. Background noise is an everyday challenge for school-age children, as typical classrooms are acoustically hostile environments. However, the hypothesis generated here is that educators may be able to help students to learn words better by reducing ambient noise levels and adopting a clear speech style.

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APPENDIX A. SAMPLE TRAINING NARRATIVE

Toy Shopping

First Exposure

Sarah and her mom were talking about the new daycare center that was being built in their town. Sarah told her mom that she wanted to do something nice for the children who would be going there. Sarah's mom thought that was really kind and wondered what Sarah had in mind. Sarah thought for a minute and suddenly got an idea. "What about if we get some toys for the kids to play with?" said Sarah. "I think that sounds like a wonderful idea, Sarah, but we will need some money to do that. Where would we get it?" asked her mom. "Well," thought Sarah, "I have money in my piggy bank from Christmas and my birthday and I think I'd like to use some of it to do this. I have lots of stuff, so I'd like to help out kids who don't have as much as I do." Sarah's mom was so proud! "Honey, I'll tell you what. I will help you pay for the toys. You can pay half and I'll pay the other half." "Oh thanks, mom! That way we can get lots of things!" Sarah's mom found a catalog on the table. "Why don't we take a look in here and find the toys we want to buy so we'll know how much money we'll need." "OK" said Sarah. She turned to the toy section and flipped through the pages while making a list of all the things she wanted to get. "Let's get a/ʃɔɪf/, a/pɛl/, a/dʒɑɪt/, a/fɪp/, a/tʃɪv/, a/dʌɪf/, a/zɛɪtʃ/ and a/gɪdʒ/." "I agree!" said her mom, who wrote down the price of each item as Sarah read the name. "OK", said her mom. "That brings us to our money limit. Shall we go shopping?" "Cool" said Sarah. She put the catalog into her mom's purse and they headed out the door.

Second Exposure

"Ok, Sarah, do you know where the toys are in here?" asked Sarah's mom. "Of course!" said Sarah, "Follow me." Sarah's mom got the catalog out of her purse and said, "OK, let's see... Here's the/dʒɑɪt/." "Good", said Sarah, "and here's the/fɪp/." "Ok, put that in the cart", said her mom. Sarah was scanning the shelves looking for the toys and suddenly said, "Mom! Here's the/tʃɪv/." "Good eye," said her mom. "Here's the/dʌɪf/. Oh, and here's the/pɛl/." "Five down, three to go" said Sarah. "I've found the/gɪdʒ/" said her mom. "I also found the/ʃɔɪf/" she continued. "The cart is getting full!" "Awesome!" said Sarah, "there's the/z e ɪtʃ/" "Great," said her mom. "Is that is?" "Yep!" said Sarah. "We got 'em all!" "Let's go check

out, then. Maybe we can grab a snack, too,” said Sarah. Her mom laughed and said, “You bet, kiddo. The snack is my treat.”

Third Exposure

Sarah’s mom knew the woman in charge of the new daycare center. When she and Sarah walked in, she introduced Sarah. “Mrs. Colby, this is my daughter, Sarah. It was her idea to buy these toys for the center.” Mrs. Colby shook Sarah’s hand and said, “It’s nice to meet you Sarah. You are a special child to be so unselfish. I just know the kids will love playing with these new toys.” “Thank you” said Sarah. “Would you like to see what we bought?” “Absolutely!” Said Mrs. Colby. “OK...here’s a/fɪp/a/ɡɪdʒ/, a/ʒeɪtʃ/, a/ʃoʊf/a/dʒaɪt/, a/pel/, a/tʃɪv/and a/dʌtʃ/,” said Sarah. Mrs. Colby was overwhelmed! “Wow!” she said, “So many things! You are such a generous person. Thank you from the bottom of my heart!” Sarah smiled a big smile. She felt very proud to have helped the new daycare center.

APPENDIX B. SAMPLE COMPREHENSION PROBE ARRAY

Target

Far semantic foil

Near semantic foil

Unrelated foil

Figure 1.
Flow chart illustrating the order of the steps in the experiment.

Figure 2. Mean number of phonemes produced correctly per word recalled (with standard error bars) when words were learned in quiet or noise with clear or plain speech input.

Table 1

Mean percentage correct and standard deviation on the comprehension probe by group, condition, and time.

<i>Listening group</i>	<i>Speech condition</i>	<u><i>Probe 1</i></u>		<u><i>Probe 2</i></u>		<u><i>Probe 3</i></u>		<u><i>Probe 4</i></u>	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Quiet	Clear	98	.13	98	.13	99	.09	99	.09
	Plain	99	.09	99	.09	100	00	100	00
Noise	Clear	97	.16	99	.09	99	.09	99	.09
	Plain	98	.13	99	.09	98	.13	99	.09