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Effects of Background Noise on Speech and Language in Young Adults

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RUNNING HEAD: EFFECTS OF BACKGROUND NOISE

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Abstract

Purpose: To investigate how different types of background noise that differ in their level of linguistic content affect speech acoustics, speech fluency, and language production for young adult speakers when performing a monologue discourse task.

Method: Forty young adults monologued by responding to open ended questions in a silent baseline and five background noise conditions (debate, movie dialogue, contemporary music, classical music, pink noise). Measures related to speech acoustics (intensity and frequency), speech fluency (speech rate, pausing, and disfluencies), and language production (lexical, morphosyntactic, and macro-linguistic structure) were analyzed and compared across conditions. Participants also reported on which conditions they perceived as more distracting.

Results: All noise conditions resulted in some change to spoken language compared with the silent baseline. Effects on speech acoustics were consistent with expected changes due to the Lombard effect (e.g., increased intensity and fundamental frequency). Effects on speech fluency showed decreased pausing and increased disfluencies. Several background noise conditions also seemed to interfere with language production.

Conclusion: Findings suggest that young adults present with both compensatory and interference effects when speaking in noise. Several adjustments may facilitate intelligibility when noise is present and help both speaker and listener maintain attention on the production. Other adjustments provide evidence that background noise eliciting linguistic interference has the potential to degrade spoken language even for healthy young adults, because of increased cognitive demands.

Introduction

Everyday communication situations often involve the presence of background noise from mobile devices, televisions, radio, traffic, or other people. Background noise may be considered a type of environmental distraction that has the potential to increase cognitive load and interfere with communication. The purpose of the present study was to investigate how different types of background noise affect spoken language for young adults during a monologue discourse task.

A number of studies suggest that background noise affects how a speech signal is received (e.g., Carroll & Ruigendijk, 2013; Howell, 2008; Sperry et al., 1997). The distracting noise that is present in the environment when we are listening to someone speak can be considered a form of masking because it interferes with the target stimuli that a listener is attempting to perceive. In this context, masking can usually be divided into two types: energetic and informational. Energetic masking refers to a listening situation in which competing noise overlaps in time and frequency in a way that parts of the speech signal become inaudible. Informational masking differs in that it occurs in a situation where the listener is unable to separate the target signal from linguistically meaningful distracters (Brungart, 2001), which results in involuntary processing of language that is unrelated to the target signal. An example of this would be an attempt to listen to a friend speak while someone nearby is also talking loudly. The involuntary processing of another person’s speech could make it hard to focus on the friend. The listener has to selectively attend to the signal, while consciously attempting to avoid distraction from the linguistic components of the informational masking they are being exposed to. For this reason, performing a task in the presence of informational masking is considered more cognitively demanding than doing so in the presence of energetic masking (Meekings et al., 2016).

The listening in noise literature, which distinguishes between energetic and informational masking, has conceptually contributed to additional research about speaking in noise. While the term *masking* has sometimes been used when discussing background noise during a speaking task (e.g., Cooke & Lu, 2010; Meekings et al., 2016), it implies a distinct masker and target. Because the present study employed a monologue speaking task in the presence of various types of background noise in contrast to the perception of a target signal, we refer to our conditions as *noise* rather than *masking* conditions. While the degree of linguistic interference has some relation to the two types of masking previously mentioned (i.e., informational masking includes linguistic interference), we have opted to describe these according to the extent of linguistic interference rather than as energetic v. informational masking. Like informational masking, we presume that greater linguistic interference will increase cognitive demands. Few studies to date, though, have investigated how different types of noise affect spoken language production.

Speaking with Environmental Distraction

Speaking involves high-order cognitive and motor processes that rely on an intricate web of neural networks (Dick et al., 2019; Longcamp et al., 2019). As such, speaking involves not only complex linguistic processing and motor activity, but also integrates other high-order cognitive systems such as attention (Cahana-Amitay & Albert, 2015). While different theories have been proposed to explain the relationship between attention and spoken language, each system seems to influence the other (Hula & McNeil, 2008; Murray, 2002; Villard & Kiran, 2016). Because of this relationship and in order to understand it better, research has begun to investigate how attention affects language processing.

Attentional demands during speech have been manipulated mostly through divided and focused attention tasks (see e.g., Bailey & Dromey, 2015; Dromey & Scott, 2016; Kemper et al., 2003, 2005). Divided attention involves performing two tasks or responding to multiple stimuli simultaneously. Focused attention, on the other hand, involves performing a single task or responding to a single stimulus while filtering out distractions. Performing a task under divided attention is more cognitively demanding—requiring greater attentional resources (Cahana-Amitay & Albert, 2015)—but focused attention is also common in everyday situations. Although many studies have investigated how divided and focused attention affect listening and language comprehension (e.g., Carroll & Ruigendijk, 2013; Janse, 2012; King & Hux, 1996; Mattys & Wiget, 2011; Sperry et al., 1997), fewer have focused on how these same attentional demands affect speech and language production.

During divided attention tasks, healthy adults experience some interference to both speech and language production (Dromey & Bates, 2005; Dromey & Benson, 2003; Kemper et al., 2003, 2005, 2009; Raffegeau et al., 2018). Effects on speech have mostly been investigated in relation to changes in kinematics during rote tasks such as sentence repetition while simultaneously performing a concurrent task. For example, Dromey and Benson (2003) reported that the completion of a manual motor task (putting together bolts, washers, and nuts) was associated with smaller and slower lip movements, whereas cognitive (mental arithmetic) and linguistic (matching verbs to nouns) tasks led to less consistent lip movement patterns during sentence repetition. A subsequent investigation (Dromey & Bates, 2005) found similar decreases in lip movement stability for speech during a linguistically challenging task (arranging words into a correct syntactic sequence) and also reported increased vocal intensity under each divided attention condition (linguistic, motoric, and cognitive activities). Similar results were reported by Bailey and Dromey (2015), who found decreased lip movement consistency, smaller lip movements, and increased vocal intensity for speech produced while completing concurrent tasks. These authors also reported decrements in the performance of cognitive and linguistic tasks when speaking as compared to performance of these tasks in isolation. In addition to affecting speech movements during rote tasks, divided attention has also been shown to interfere with language during running speech.

Unlike kinematic studies of speech production, the effects of divided attention on language have been mostly investigated within the context of discourse. Findings suggest that divided attention tasks tend to decrease fluency and grammatical complexity for healthy adults with greater effects on grammatical complexity and less on fluency for young adult speakers (Kemper et al., 2003, 2005, 2009). For example, across a number of tasks that were concurrently performed while monologuing (i.e., walking, walking while carrying groceries, climbing stairs, finger tapping, visual tracking), young adults reduced the number of clauses they produced per utterance while often maintaining a relatively consistent speech rate. Although while performing the same concurrent tasks older adults generally decreased their rate with little effect on grammatical complexity (Kemper et al., 2003, 2005), young adults have also shown some interference to their fluency when the level of challenge associated with the concurrent task increased (e.g., walking while avoiding obstacles v. walking only; Raffegeau, Haddad, Huber, & Rietdyk, 2018). Like allocating attention to another task while talking, focusing on talking in the face of distracting stimuli is another common communication scenario.

Speaking in Noise

Speaking in noise engages focused attention, which allows the speaker to selectively attend to one task while filtering out unrelated or distracting stimuli. Although this is considered less cognitively demanding than divided attention (Cahana-Amitay & Albert, 2015), research to date indicates that, similar to divided attention, focused attention results in some interference on speech (Dromey & Scott, 2016; Hanley & Steer, 1949; Kemper et al., 2003; Lu & Cooke, 2008, 2009). Similar to much of the divided attention research, though, these findings have mostly focused on changes in speech movements and acoustics during rote speech tasks such as sentence repetition with less empirical investigation focused on how noise affects spoken language during communicative discourse.

A number of studies have demonstrated significant effects of different types of background noise on speech acoustics (e.g., intensity and frequency) and speech fluency for young adults when engaged in sentence reading and sentence repetition. For example, Lu and Cooke (2008, 2009) found that young adults increased the intensity and frequency of their speech when repeating and reading sentences across a number of different noise conditions (1-talker, 2-talker, 4-talker, 8-talker, 16-talker, and speech-shaped noise that was high- or low-pass filtered or included the full spectral band). Generally, as the noise approached the more intense speech-shaped noise, the intensity and frequency of the speech signal from the participant also increased. The authors suggested that acoustic adjustments that the speaker makes may be intended to make them more intelligible in the face of masking (Lu & Cooke, 2008, 2009). In addition to changes in speech acoustics, young adults may increase their speech rate when performing rote speech tasks in the presence of concurrent noise (Dromey & Scott, 2016; Hanley & Steer, 1949). For example, when repeating sentences across four noise conditions (1-talker, 2-talker, 6-talker, and pink noise) Dromey and Scott (2016) found that sentence duration significantly decreased in the 1-talker noise condition. They suggested that this may have been a compensatory response to the increased attentional demands of the distracting noise in the condition with greater linguistic interference.

Building on much of this work, additional research has expanded on the notion of potential speaker adjustments to increase listener comprehension by investigating how noise that varies in its degree of linguistic interference affects more ecologically valid speech tasks. For example, Cooke and Lu (2010) asked 8 adult speakers (4 M, 4 F) to solve sudoku puzzles while communicating their process out loud across four conditions: silence, competing speech, speech-shaped noise, and speech-modulated noise. In each different condition, participants solved puzzles both alone (monologuing) and in pairs (dialoguing). Findings included increased fundamental frequency, and more and longer pauses when speaking in the noise conditions compared to silence. Additionally, when dialoguing v. monologuing, participants adjusted the timing of their speech to reduce temporal overlap with the competing speech signal, shortened word durations, and increased their intensity in what the authors suggested was an attempt to modify speech to help the conversational partner understand in noisy backgrounds. Similarly, Hazen and Baker (2011) investigated the effects of both vocoded speech (intended to simulate a listener with a cochlear implant) and babble speech (intended to simulate a noisy listening environment) on rote (sentence reading) and communicative (discussing differences in picture stimuli with a partner) tasks. They found that conversational speech was more finely modulated than speech without communicative intent, as evidenced by speakers varying their strategies and matching their speech to the listeners' needs. They also found increased F_1 range and mean energy for the babble speech condition, suggesting that the way the environment affects sound is not always detrimental and that speaking clearly can help compensate for poor acoustic characteristics of the environment.

Despite these important findings about how environmental noise affects speech acoustics and speech fluency and the increased interest in communicative tasks, there is a paucity of research regarding how noise affects spoken language for young adults. One study investigated the effects of a competing background conversation on a dyad's conversational interaction. While no lexical or morphosyntactic variables were included, speakers were found to experience more disruptions to the timing of their speech (i.e., increased disfluencies, entering the conversation at inappropriate points of time) and greater numbers of interruptions during the conversational exchange (Aubanel et al., 2011). A second study emphasized divided attention, but also included two conditions where participants were asked to monologue while (1) ignoring a single-talker and (2) ignoring cafeteria noise. In addition to decreased speech rate in both noise conditions, findings revealed significantly decreased grammatical complexity, which was more pronounced for the ignoring speech than the ignoring cafeteria noise condition. Additionally, ignoring speech led to significantly decreased lexical diversity (Kemper et al., 2003).

Given the relevance of focused attention tasks to everyday communication, understanding how noise affects both speech and language for young adults during a naturalistic discourse task is warranted. Previous research suggests that noise conditions with both low and high levels of linguistic interference might affect speech and language production, but these effects have rarely been considered in tandem. Rather, the effect of noise on speech acoustics has been investigated with increasing interest in communication-focused tasks but there have been few attempts to also measure language. In addition, relatively little is known about how different types of noise influence spoken language production. The purpose of the present study was to investigate how different background noise conditions that varied in their degree of linguistic interference affect spoken language for young adult speakers when performing a monologue discourse task.

Method

Participants

Forty neurotypical young adults (20 males and 20 females), all native speakers of American English, participated in the study. The mean age was 25 years (*SD* = 2) for men and 24 (*SD* = 1) years for women. None of the participants reported any history of language, speech, or hearing disorders. Each passed a hearing screening bilaterally at 25 dB HL at 500, 1000, and 2000 Hz. Each participant gave written consent to participate in the experiment, which was approved by the university institutional review board.

Instrumentation

Participants sat in a sound attenuating booth to provide an optimal environment to make high quality acoustic recordings and reduce auditory distractions outside of the presented stimuli. The participants were exposed to the experimental audio conditions through headphones, and their speech was recorded with a boom microphone approximately 50 cm from the mouth. A sound level meter was placed 100 cm from the mouth to allow a reference recording to subsequently calibrate speech intensity during acoustic analysis of the microphone signal. This signal was digitized with a FocusRite Scarlett 2i2 USB analog to digital converter at 44,100 Hz and Audacity software version 2.3.1. To establish the intensity level of the stimuli, the pink noise stimulus was perceptually matched to the loudness of 1 kHz centered masking noise from an audiometer at 75 dB HL. After the intensity level was established, all of the stimuli were equalized in peak amplitude to the pink noise using Audacity in order to avoid presenting stimuli of different loudness levels during the experiment.

Procedures

Each participant completed experimental tasks within a one-hour session. Participants were given a list of 55 open-ended questions prior to data-collection and were asked to circle 8-

10 topics they felt comfortable speaking about (see Appendix A). Six prompts were then selected and verbally presented in a random order by the experimenter, and the participants were asked to answer at a comfortable speaking rate and loudness. Participants answered each open-ended question as a monologue in one of six different conditions: two speakers having a debate, dialogue from a movie, contemporary music, classical music, pink noise, and a silent-baseline condition. We have ordered these conditions here in what we hypothesized was greatest to least linguistic interference. The debate stimulus consisted of two sports commentators arguing about the merits of two basketball players. The dialogue was taken from a contemporary movie likely to be familiar to the participants. In each case, both speakers were intelligible throughout the duration of the sample. The contemporary music stimulus was a lively and upbeat song with English lyrics. Given the lyrics, we considered this sample as presenting noise that combined linguistic and nonlinguistic elements. The classical music was characterized by a wide dynamic range and included both instrumental and Latin vocal components. We considered this and the pink noise sample to present no linguistic interference. All noise stimuli were presented at 75 dB HL and pauses longer than 200 ms were removed to ensure continuity. The samples were presented in the following fixed order for all participants: silent, pink noise, movie, debate, classical music, contemporary music. At the end of the session, each participant identified which condition they perceived as most distracting. Answers were then tallied to gain insight into participants' subjective experience.

Prior to data analysis, pauses in between questions, nonspeech behaviors (coughing, laughing, etc.), and experimenter speech were removed from the recordings using Praat (Boersma & Weenink, 2014). These recordings were used to analyze speech acoustics and were also orthographically transcribed verbatim for the purpose of language analysis. Orthographic transcriptions were segmented into C-units, which are syntactic units consisting of an independent clause and any associated dependent clauses or modifiers. To ensure strong reliability, research personnel followed the step-by-step procedures for C-unit segmentation outlined in Wright and Capilouto (2012). Using the segmented orthographic transcriptions, two research assistants coded the transcripts for phonological, lexical, grammatical, and macro-level errors in the Codes for Human Analysis of Transcripts (CHAT) format (MacWhinney, 2000). The coding format followed that reported by Marini, Boewe, Caltagirone, and Carolomagno (2005). Before coding, the two research assistants completed a standard set of 10 practice transcriptions which they segmented into C-units and coded for CHAT errors. These practice transcriptions were compared to master transcriptions completed through collaboration between the first and third authors. Once research assistants were in agreement with the master transcriptions, they began coding new files. The third author, who has 4 years of experience with language analysis, reviewed each coded transcription for accuracy and made revisions in consultation with the first author. This is similar to CHAT coding approaches reported previously (e.g., Fromm et al., 2017) and ensured that accuracy was prioritized over agreement.

Dependent Variables

Dependent variables included measures of speech acoustics, speech fluency, and language production. Table 1 summarizes these measures, which are also explained below.

Speech Acoustics. Acoustic measures of connected speech, including characteristics of intensity and frequency were computed and analyzed to quantify features of speech performance. Intensity variables were the *M* and *SD* of the monologue intensity in dB SPL at 100 cm in each experimental condition. In order to avoid including pauses or nonspeech sounds in the intensity measurements, a dB floor was selected based on the intensity level of the softest speech sounds in each response. The Praat intensity listing for the monologue was exported as a comma separated values file (csv) with dB values reported at 5 ms intervals. This listing was brought into a Matlab application (version 9.0) to compute the *M* and *SD* of the intensity above the dB floor; thus, dB values below the level identified as the softest speech sounds were not included in the *M* and *SD* computation. Fundamental frequency (F_0) was computed by taking the *M* and standard deviation *SD* under each experimental condition, with F_0 being manually edited when necessary to overcome tracking errors. Praat provided a voicing report with the *M* and *SD* of the F_0 in Hz. Sex differences were accounted for in F_0 variability by converting the *SD* in Hz into semitones with a spreadsheet equation.

Speech Fluency. Measures of speech fluency accounted for various aspects of the speed at which connected speech was produced as well as interruptions to the flow of speech. Speech rate was defined as the number of words produced (excluding those which were part of repetitions or revisions) per minute. Pause time ratio (PTR) was defined as the proportion of sample time spent in silent pauses greater than 200 ms. This was measured using a Matlab application, which computed the RMS contour of the entire monologue (after manual removal of laughter, coughing, and other non-speech sounds), normalized the RMS contour by assigning the peak value for the entire recording as 100, then used 10% of the RMS peak amplitude to separate speaking from pausing (amplitude values below were defined as pausing and above were defined as speaking). This approach for measuring PTR has been described previously and was found to have good agreement with manual tagging of the onset and offset of speech (Dromey et al., 2008). The disfluency ratio accounted for the number of false starts and simple repetitions (e.g., repeated sound, syllable, or word) produced per word and multiplied by 100 to express as a percentage. These types of disfluencies are among the less commonly produced by typical speakers (Conture, 2001) and may indicate interference in planning, programming, and executing speech whereas silent pauses may relate more to language formulation (Hird & Kirsner, 2008).

Language Production. Verbatim orthographic transcriptions were analyzed for the Moving Average Type-Token Ratio (MATTR) using the computer analysis for psychological research (Covington, 2007; Covington & McFall, 2010). MATTR is a validated measure of lexical diversity (Fergadiotis et al., 2013) that accounts for variability in text length. The window length was set at 100 words to account for the shortest sample in the dataset. CHAT transcripts were analyzed using CLAN software (MacWhinney, 2000) to obtain measures of lexical errors, grammatically correct words, and coherent utterances. Lexical errors accounted for the number of false starts, incorrect word productions, simple repetitions, and fillers produced per word. All of these errors are considered to reflect problems with phonological-semantic processing. Grammatically correct words accounted for the proportion of words produced that were not substitutions or omissions of function words, substitutions of bound morphemes, and omissions of content divided by the total number of words. Coherent utterances accounted for the proportion of utterances without macro-linguistic errors (i.e., incomplete, ambiguous, tangential, incongruent, repeated, or filler utterances) divided by total number of utterances.

Statistical Analysis

Results were analyzed using two-way mixed-effects analyses of variance (ANOVAs): The between-subject factor (Group) accounted for differences between male and female participant groups; the within-subject factor (Condition) accounted for differences across the different background noise conditions; participants were included as a random effect factor. All statistical analyses were completed using R 3.4.1 (R Core Team, 2017). Mixed-effects ANOVAs were completed on models built using the lme function within the nlme package (Pinheiro et al.,

2017) and pairwise comparisons using Tukey's HSD were made on the model with the emmeans package (Lenth, 2017).

Results were further analyzed using a relative change score that compared performance between silent and noise conditions. This score was calculated by dividing the difference in value between noise and silent conditions for a given variable by the silent condition value and then multiplying by 100 to express as a percentage (Kemper et al., 2005). We will refer to this score in the present study as the background noise effect. Because higher values indicated unfavorable changes for PTR, disfluency ratio, and lexical errors (i.e., more pausing, disfluencies, and lexical errors), background noise effect scores were inverted for these variables so that negative background noise effects indicated that performance deteriorated in the corresponding noise condition (i.e., background noise costs), whereas positive background noise effects indicated that performance improved (i.e., background noise benefits). Background noise effects for each group were analyzed using one-sample t-tests to determine whether performance changed significantly. Because independent t-tests were conducted on each dependent variable across the five noise conditions, we used a Bonferroni adjusted alpha level of .01 (.05/5).

Results

Several group and condition effects were found with regard to measures of speech and language. There were no interaction effects. All background noise conditions had some effect on speech acoustics, speech fluency, and/or language production during the monologue discourse task. Because the primary aim of the present study was to determine how background noise affects spoken language, we emphasize condition effects below. Group effects, however, were also seen with females higher than males for fundamental frequency ($F[1,38] = 317.087$, $p < .001$, $\eta^2_p = .89$) and grammatically correct words ($F[1,38] = 9.587$, $p = .004$, $\eta^2_p = .20$), and males higher than females for lexical diversity (F[1,38] = 4.182, $p = .048$, $\eta^2_p = .10$). Descriptive statistics for all dependent variables are reported in Table 2. Background noise effects are illustrated in Figure 1.

Speech Acoustics

Background noise led to significant changes in speech acoustic measures related to both intensity and fundamental frequency.

Intensity

Main effects for condition were found for both mean intensity (F[5,190] = 52.348, $p < .001$, $\eta^2_p = .58$) and intensity standard deviation (F[5,190] = 29.742, $p < .001$, $\eta^2_p = .44$). Pairwise comparisons revealed an increase in mean intensity under each condition compared with the silent condition ($p < .001$). Background noise effects for mean intensity also showed statistically significant increase from zero across all noise conditions ($p < .001$). Pairwise comparisons showed that standard deviation of intensity also increased from silent to pink ($p < .001$), contemporary music ($p < .001$), and classical music ($p = .02$) conditions. Background noise effects confirmed this finding with significant changes from zero across the same conditions ($p < .002$).

Fundamental Frequency

Overall, there were significant changes in mean F_0 across conditions (F[5,190] = 16.757, $p < .001$, $\eta^2_p = .31$). Pairwise comparisons revealed a significantly increased F_0 compared with the silent condition in classical, debate, contemporary music, and pink noise conditions ($p < .001$); however, an increase in F_0 was not seen in the movie condition ($p = .104$). Background noise effects, though, were found to be significantly greater than zero for all noise conditions (p

< .001) suggesting that even the movie condition led to some increase in mean F_0. No main, interaction, or background noise effects were seen for semitone standard deviation measures.

Speech Fluency

The effect of background noise on speech fluency was manifest by changes in pause time and disfluencies. Analysis of speech rate, on the other hand, revealed no change across conditions and no background noise effects.

Pause Time Ratio

Overall, there were significant differences in pause time across conditions ($F[5,190] = 6.487$, $p < .001$, $\eta^2_p = .15$). Pairwise comparisons revealed that participants paused more in the silent than all other conditions ($p < .01$) except the classical music condition ($p = .347$). Background noise effects confirmed these findings revealing significant change from zero for all noise conditions ($p < .01$) except the classical music condition ($p = .47$).

Disfluency Ratio

A main effect for condition was found for disfluencies ($F[5,190] = 3.389$, $p = .006$, $\eta^2_p = .08$) with pairwise comparisons revealing more disfluencies in the debate compared with the silent ($p = .039$) and pink noise ($p = .007$) conditions. Analysis of background noise effects expanded on these findings to reveal significant changes from zero across all noise conditions ($p < .01$) except pink noise ($p = .03$).

Language Production

Background noise also had an effect on language production. Changes were found across measures of lexical diversity and grammatically correct words. Lexical errors and coherent utterances were also analyzed.

Lexical Diversity

A main effect for condition was found for lexical diversity ($F[5,190] = 4.364$, $p < .001$, $\eta^2_p = .10$) with pairwise comparisons revealing greater lexical diversity compared with the silent condition for debate, contemporary music, and pink noise conditions ($p < .05$). Analysis of background noise effects for lexical diversity showed statistically significant changes from zero across all noise conditions ($p < .01$) except the classical music condition ($p = .012$).

Lexical Errors

No main effect for condition was found for lexical errors; however, participants did generally produce more lexical errors in the debate and movie conditions than all other conditions. Background noise effects revealed no statistically significant changes from zero.

Grammatically Correct Words

For grammatically correct words, a main effect revealed differences among conditions ($F[5,190] = 5.263$, $p < .001$, $\eta^2_p = .12$). Post hoc analysis revealed that participants produced significantly fewer grammatically correct words when speaking in the debate condition compared with silent ($p < .001$), movie ($p < .001$), and contemporary music ($p = 0.005$) conditions. Analysis of background noise effects confirmed statistically significant decrease from zero for the debate condition ($p < .001$).

Coherent Utterances

Although no main effects were found for proportion of coherent utterances, participants trended toward more macro-linguistic errors in the contemporary music compared with the silent condition ($p = .064$). Similarly, no significant background noise effects were found, but the greatest numerical change in coherent utterances was seen in the contemporary music condition.

Subjective Judgments

When asked to rate which of the five noise conditions they perceived as "most distracting," participants most frequently selected debate and contemporary music conditions. Some participants also selected the movie condition and one selected the pink noise condition. Eight participants perceived two of the conditions as equally distracting and were allowed to respond by selecting both. Results are reported in Table 3.

Discussion

Everyday communication commonly occurs in noisy environments; however, to our knowledge, with the exception of one small-scale study (Aubanel et al., 2011), the effects of background noise on both speech and language have not been reported together in the same study. The present investigation aimed to determine how noise conditions that varied in their degree of linguistic interference and simulated noises from everyday communication environments affected speech acoustics, speech fluency, and language production for young adults when performing a monologue discourse task. Findings suggest both compensatory responses and interference effects.

Compensatory Responses to Noise

Some of the changes that young adult participants made to their speech could be interpreted as facilitating communication through improved intelligibility and changes to aspects of production intended to capture the listener's focus in the face of distracting noise. These changes were manifest in increased intensity and fundamental frequency, decreased silent pausing, and increased lexical diversity.

The effects of background noise on speech acoustics were consistent with expected changes due to the Lombard effect (Summers et al., 1988). Both men and women increased their mean intensity and F_0 when monologuing in background noise conditions. Relative to other noise conditions, these changes were more marked in the contemporary music and pink noise conditions. The pink noise condition, specifically, caused the most significant increase in intensity. Consistent with previous research, this suggests that the Lombard effect may be most pronounced when the energetic component of noise is increased (Cooke & Lu, 2010).

In addition to general changes in speech acoustics due to the Lombard effect, speakers in the present study seemed to make more specific adjustments to their prosody—specifically while speaking in noise conditions that contained no or little linguistic interference. Across all conditions that involved nonlinguistic noise (pink noise, contemporary music, classical music), standard deviation of intensity increased. This increased variability in intensity may have resulted from participants emphasizing specific words in these conditions to increase the intelligibility of their production. This would be consistent with findings from a previous study showing that speakers significantly manipulated specific intensities in trisyllabic words to increase contrastivity of adjacent syllables when exposed to background noise with little or no linguistic interference as compared to a silent baseline (Arciuli et al., 2014).

The effects of background noise on silent pausing and lexical diversity suggest additional ways that speakers potentially adjusted their production to improve communication. Contrary to our hypothesis, participants paused less in all noise conditions except the classical music condition. We had anticipated that because of the heightened cognitive demands related to speaking in noise, young adults would have paused more. Kemper et al. (2003) found that young adults decreased their speech rate when monologuing in noise. However, young adult participants in their study listened to noise at an average intensity of 40 dB HL whereas the present study presented noise at 75 dB HL. Dromey and Scott (2016), on the other hand, presented noise at a moderate intensity (65 dB HL) and found that participants spoke more quickly in the one-talker noise condition. It is possible that participants pushed through the speaking task with less pausing in an attempt to maintain the listener's attention or increase their own ability to focus on the speaking task without becoming distracted (Varadarajan & Hansen, 2006). It is also important to note that in the present study, speech rate remained constant while silent pauses decreased. This suggests that participants were possibly extending their production over longer periods of time, which may have afforded them increased processing time without the silent pauses. To explore this possibility, we calculated articulation rate as the number of words produced divided by minutes of speaking time during the sample. Numerically, mean articulation rate was lower for all noise conditions except the classical music condition, but none of the differences were statistically significant.

Similar to the effects on silent pausing, the effects of noise on lexical diversity were the opposite of what we originally hypothesized. Across two noise conditions, Kemper et al. (2003) found that young adult participants either maintained or reduced their lexical diversity, but their type-token ratio metric would have been heavily influenced by variability in sample length. In contrast, participants in the present study increased their lexical diversity. Although the cause of this increase cannot be ascertained from our data, we offer two possibilities. First, similar to decreased pause time, the increase could reflect an effort to engage the listener or increase the speaker's own focus on the task. Second, it may reflect an increase in circumlocution (e.g., "industry of the community that we live in" for "local economy") in distracting noise conditions.

Interference Effects of Noise

In contrast to the variables that showed some apparently compensatory responses, others revealed changes in speech production that could be interpreted as unfavorable. For example, when compared with a silent baseline condition, all background noise conditions resulted in either disruption to the forward flow of speech, decreased accuracy of language production, or both. Generally, linguistic accuracy seemed to be more volatile when linguistic interference associated with the background noise was high.

Across all conditions except pink noise, participants in the present study interrupted their forward flow of speech more with simple repetitions and false starts than in the silent condition. In light of the decreased pausing, it seems logical to suggest that increased disfluencies were merely a result of decreased pausing. A post-hoc correlation analysis, however, revealed no significant correlation between background noise effects for pause time ratio and background noise effects for the disfluency ratio ($r = .13$). This suggests that changes in disfluencies were independent of changes in pausing. Perhaps a more compelling suggestion is that the distracting noise conditions caused participants to have more difficulty planning, programming, and executing speech effectively. For example, the increased disfluencies could indicate less motoric precision when speaking in noise, leading to disfluent behaviors that reflect covert repairs (Postma & Kolk, 1993). This suggestion is consistent with previous studies that showed decreased lip movement stability and consistency during speaking conditions that were attentionally demanding (Bailey & Dromey, 2015; Dromey & Bates, 2005; Dromey & Benson, 2003).

Noise conditions with greater linguistic interference seemed to have more effect on micro-linguistic accuracy. In the debate condition, participants produced fewer grammatically correct words. While not statistically significant, the highest background noise costs for lexical errors were found in the debate and movie conditions. Because speaking in the presence of noise that contains linguistic elements is more cognitively demanding (Meekings et al., 2016), we expected some interference on measures of language in these conditions. In addition to the increased cognitive demands in these conditions, it may be that young adults are more accustomed to speaking in some noise conditions than others. For example, they may be more used to speaking with music in the background, so the linguistic processing in the contemporary and classical music conditions were not affected as much, despite the contemporary music also containing linguistic elements. The effects of noise on grammatically correct words in the present study are consistent with previous findings that suggest that young adults tend to decrease their mean clauses per utterance and developmental level (both measures of grammatical complexity) when completing complex divided and focused attention tasks including ignoring 1-talker speech and speech-shaped noise (Kemper et al., 2003, 2005).

Although no noise condition was found to significantly affect coherent utterances, the greatest decrease was manifest in the contemporary music condition. Despite participants reporting that this was one of the most distracting conditions, they were generally able to produce utterances that were accurate in lexical and morphosyntactic domains. To some extent, however, their macro-level organization did seem to suffer. More data would be needed to determine whether this trend was meaningful.

In conclusion, background noise that varied in degree of linguistic interference led to compensatory responses and interference effects on spoken language; however, decrements to language production were generally greater for noise that involved linguistic components.

Implications for Future Research and Clinical Practice

Because communicating in noise is a common everyday occurrence, it is important to understand how noisy communication environments affect spoken language. The present study combined measures of both speech and language to analyze these effects in male and female young adult speakers. Several limitations in the present study could be addressed in future research. First, testing across a range of dB levels would have allowed for better understanding of the effects of noise conditions presented in different modes. Second, the same sequence of noise conditions was presented to all of the participants, which could have led to an order effect. Third, auditory stimuli (a) were described according to the degree of suspected linguistic interference rather than by their acoustic features and (b) varied in their dynamic range of intensity. Fourth, there could have been some variability in the intensity measures because participants were able to move their heads during the recordings, which could have affected the mouth-to-microphone distance, although a systematic effect seems unlikely. Lastly, it would be beneficial in a follow-up study to analyze the timing of the participants' speech relative to the stimuli being played to assess spectral and/or temporal overlap and build on previous studies investigating whether speakers can time their productions to take advantage of pauses in the background audio (Lu & Cooke, 2009).

Because speaking in noise is an everyday experience, findings from this study also form an important foundation for investigating the effects of environmental noise on the spoken language of disordered populations. For example, people with aphasia perform significantly worse than their neurologically healthy peers during divided attention tasks (Harmon et al., 2019; Murray et al., 1998) and complain about the challenge of communicating in noisy environments (Baylor et al., 2011; Garcia et al., 2000; Harmon, 2020), but the quantitative effects of noise on their spoken language have not yet been reported. Furthermore, integrating background noise into speech therapy for adults with cognitive-linguistic communication disorders might help with maintenance and generalization. Clinicians could also rely on information about which noise conditions are most challenging for disordered populations to up the ante over time by systematically introducing new noise stimuli intended to be more distracting.

Conclusions

The present study revealed that different types of background noise led to both compensatory responses and interference effects on speech and language in young adult speakers. What could be considered compensatory responses mostly related to the Lombard effect, whereas interference effects related to speech fluency and linguistic accuracy. While some changes were seen across all noise conditions, interference in language production was most prominent for noise conditions that had a high degree of linguistic interference (particularly the debate condition). These findings confirm that noise affects spoken language for young adults and suggest that cognitive demands associated with the noise influence language production. Speech therapy, which is often conducted in a quiet, distraction-free environment, may result in improved generalization if, after mastery of a trained skill, clinicians integrate distracting noise into therapy to simulate everyday communication challenges and increase the cognitive load.

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Table 1. Dependent variables and associated definitions

Construct	Variable Name	Definition
Speech Acoustics	Intensity (dB)	Mean intensity (SPL at 100 cm)
	Intensity standard deviation (dBSD)	Intensity variability
	Fundamental frequency (F_0)	Mean F_0
	Semitone standard deviation (STSD)	Normalized F_0 variability during the sample
Speech Fluency	Speech rate	Words per minute
	Pause time ratio (PTR)	Proportion of time spent in silent pauses greater than 200 ms during the sample
	Disfluency ratio	Number of false starts and simple repetitions per verbalization multiplied by 100
Language Production	Lexical Diversity	Moving Average Type-Token Ratio (MATTR), which measures lexical diversity using the type-token ratio while accounting for variability in sample length (Covington & McFall, 2010)
	Lexical errors	Proportion of lexical-phonological errors (false starts, incorrect word productions, simple repetitions, fillers) per verbalization
	Grammatically correct words	Proportion of words produced without morphosyntactic errors (function word omissions and substitutions, bound morpheme substitutions, content omissions)
	Coherent utterances	Proportion of utterances produced without macro-linguistic errors (incomplete, ambiguous, tangential, incongruent, repeated, or filler utterances)

Table 2. Descriptive Statistics for all dependent variables by Sex and Condition

	Silent		Pink Noise		Classical Music		Contemporary Music		Movie		Debate	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
dB	68.8	0.76	72.2	0.72	69.9	0.76	71.3	0.75	70.0	0.75	70.8	0.75
dBSD	5.27	0.15	6.19	0.16	5.57	0.14	6.00	0.14	5.45	0.15	5.50	0.14
F_0	158	7.62	168	7.38	165	7.37	171	7.49	162	7.33	165	7.25
STSD	2.43	0.08	2.50	0.09	2.57	0.09	2.56	0.09	2.50	0.09	2.51	0.10
Speech Rate	171	4.23	167	4.26	172	3.73	168	3.99	170	3.66	173	4.16
PTR	0.27	0.01	0.22	0.01	0.24	0.01	0.20	0.02	0.22	0.02	0.22	0.02
Disfluency Ratio (%)	0.60	0.11	0.51	0.10	0.61	0.10	0.69	0.12	0.84	0.18	1.04	0.16
Lexical Diversity	0.61	0.01	0.64	0.01	0.63	0.01	0.64	0.01	0.63	0.01	0.64	0.01
Lexical Errors	0.08	0.01	0.08	0.01	0.07	0.01	0.08	0.01	0.09	0.01	0.09	0.01
Grammatically Correct Words	0.995	0.001	0.991	0.001	0.992	0.002	0.994	0.001	0.995	0.001	0.988	0.002
Coherent Utterances	0.92	0.02	0.88	0.02	0.91	0.02	0.82	0.04	0.87	0.03	0.86	0.03

Note. F = female; M = male; dB = mean intensity (SPL at 100 cm); dBSD = intensity standard deviation; F_0 = mean fundamental frequency; STSD = semitone standard deviation; PTR = pause time ratio

Table 3. Participant Responses for the Most Distracting Stimulus Condition

	Silent	Pink Noise	Classical Music	Contemporary Music	Movie	Debate
Male	0%	0%	0%	50%	5%	55%
Female	0%	5%	0%	55%	25%	45%
Total	0%	3%	0%	53%	15%	50%

Note. Eight participants reported two stimulus conditions being equally distracting, causing the percentages to equal more than 100%.

Figure 1. Background noise effects on measures of speech acoustics, speech fluency, and language production during monologue across five conditions. A positive change represents background noise benefits and a negative change represents background noise costs. Background noise effect means and standard errors for grammatically correct words were multiplied by 10 to aid in visualization. Error bars indicate standard error. Asterisks above and below bars show significant background noise effects on that measure for the specified condition (i.e., $p < .05$). dB = mean intensity; dBSD = intensity standard deviation; F0 = mean fundamental frequency; PTR = pause time ratio.

Appendix. List of Potential Monologue Prompts.