The benefit to speech intelligibility of hearing a familiar voice

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Abstract

Previous experience with a voice can help listeners understand speech when a competing talker is present. Using the Coordinate-Response Measure (CRM) task (Bolia, 2000), Johnsrude et al. (2013) demonstrated that speech is more intelligible when either the target or competing (masking) talker is a long-term spouse than when both talkers are unfamiliar (termed ‘familiar-target’ and ‘familiar-masker’ benefits, respectively). To better understand how familiarity improves intelligibility, we measured the familiar-target and familiar-masker benefits in older and younger spouses using a more challenging matrix task, and compared the benefits listeners gain from spouses’ and friends’ voices. On each trial, participants heard two sentences from the Boston University Gerald (Kidd et al., 2008) corpus (“<Name> <verb> <number> <adjective> <noun>”) and reported words from the sentence beginning with a target name word. A familiar-masker benefit was not observed, but all groups showed a robust familiar-target benefit and its magnitude did not differ between spouses and friends. The familiar-target benefit was not influenced by relationship length (in the range of 1.5–52 years). Together, these results imply that the familiar-target benefit can develop from various types of relationships and has already reached a plateau around 1.5 years after meeting a new friend.

Keywords: speech perception, speech intelligibility, speech in noise, perceptual organization, voice familiarity

Public Significance Statement

Listeners often face the challenge of understanding speech in the presence of competing sounds, and prior experience with a talker's voice substantially improves intelligibility. We are the first to show that familiarity with a friend's voice improves intelligibility as much as does familiarity with a long-term spouse’s voice. Thus, intelligibility of a familiar voice appears to develop within the first year of knowing someone and remain constant as we speak to someone for longer periods of time.

Introduction

Verbal communication frequently occurs in listening environments in which multiple sounds occur simultaneously, such as in the presence of competing talkers. To understand speech in these "cocktail party" environments, we must be able to separate these simultaneous sounds and attend to the target speech (Cherry, 1953). In favorable listening conditions, such as those with minimal background noise, listeners with normal hearing can segregate a voice from a mixture of sounds in order to successfully carry on a conversation. In more challenging situations—such as when competing sounds are more intense than target speech, when there are several simultaneous talkers, or when listeners have hearing impairment—intelligibility of target speech is poorer (Brungart, 2001; Dubno, Dirks, & Morgan, 1984; Glyde et al., 2015; Van Engen & Bradlow, 2007), perhaps reflecting difficulty communicating in real-life settings with similar acoustic conditions.

Experience with a talker's voice improves the intelligibility of speech when competing sounds are present (e.g., Gass & Varonis, 1984; Holmes, Domingo, & Johnsrude, 2018; Johnsrude et al., 2013; Kreitewolf, Mathias, & von Kriegstein, 2017; Newman & Evers, 2007; Nygaard, Sommers, & Pisoni, 1994; Souza, Gehani, Wright, & McCloy, 2013; Yonan & Sommers, 2000). In the earliest studies that showed this intelligibility benefit for familiar voices (Nygaard & Pisoni, 1998; Nygaard et al., 1994) and in a more recent study (Kreitewolf et al., 2017), participants were trained in the lab with novel voices. Although these studies demonstrate that experience with a talker's voice improves speech intelligibility, they might underestimate the extent to which a naturally familiar voice can enhance intelligibility: Unlike trained voices, listeners experience naturally familiar voices in a variety of acoustic settings with different masking sounds and hear them over longer periods of time; across several months or years.

Johnsrude *et al.* (2013) examined the speech intelligibility benefit for naturally familiar voices with which listeners had extensive experience: that of a long-term spouse that the listener had been married to for more than 18 years. First, all participants recorded sentences from the Coordinate-Response Measure (CRM; Bolia, Nelson, Ericson, & Simpson, 2000) matrix test, which is a closed-set test often used in multi-talker intelligibility research (e.g., Best, Thompson, Mason, & Kidd, 2013; Brungart, Simpson, Ericson, & Scott, 2001; Kitterick, Bailey, & Summerfield, 2010; Mesgarani & Chang, 2012) and contains sentences in the form "Ready <call sign>, go to <colour> <number> now" (e.g., "Ready Baron go to red two now"). In the listening part of the study, participants heard two CRM sentences simultaneously and reported the colour-number coordinate spoken by the voice that said the callsign "Baron". Intelligibility of the target was better when either the target (familiar-target condition) or masker (familiar-masker condition) were in the spouse's voice than when both voices were unfamiliar (baseline condition).

Since a benefit of familiarity was observed even when the familiar voice was not the focus of attention (i.e. in the familiar-masker condition), Johnsrude *et al.* (2013) concluded that the benefit of a familiar voice probably arises because voice familiarity facilitates stream segregation. The alternative explanation, that voice familiarity merely facilitates extraction of a familiar voice from a mixture, is only possible if the voice to be extracted (i.e., that which matches a mental 'template' generated by previous exposure to the talker) is the focus of attention (Bregman, 1990). Another possibility is that listeners track and remember the color and number from both the target and masker voice, and the familiar voice indicates which pair to report. Interestingly, the intelligibility benefit derived from a familiar masker voice (familiar-masker benefit) in Johnsrude *et al.* (2013) was driven by younger listeners (aged 59 years and below): in general, the majority of errors on this task were words from the masker sentence, but younger listeners were less likely than older ones to mistake the masker voice for the target when the masker was their spouse (familiar-masker condition) than when the masker was also unfamiliar (baseline condition).

In contrast, Newman and Evers (2007) found a speech intelligibility benefit when a naturally familiar voice was the target but *not* when it was the masker. In this experiment, young participants were asked to shadow stories or isolated words spoken by their psychology professor. At the same time, they heard a story spoken by a different person who was unfamiliar to all participants. Participants who had taken classes with the professor made fewer shadowing errors than participants who had taken classes with a different professor. However, in a follow-up experiment in which the professor's voice was presented as the masker, and participants had to shadow the unfamiliar voice, there was no difference in the number of errors between participants who were and those who were not familiar with the professor's voice.

One possible reason why Johnsrude *et al.* (2013) observed a familiar-masker benefit and Newman and Evers (2007) did not is that the professor's voice was not as familiar as the spouses' voices in Johnsrude *et al.* (2013). Perhaps only a highly familiar voice that has personal significance (such as that of a spouse) can aid perceptual organization and improve intelligibility when it is the masker. Perhaps a professor's voice, only encountered in a formal setting during classroom lectures, can be picked out of a mixture when it is attended but is not familiar enough to aid perceptual organization and thereby improve performance when it is the masker.

In addition, the CRM task used in Johnsrude *et al.* (2013) has different psychometric properties to the non-matrix tasks such as those used in Newman and Evers (2007), Levi, Winters, and Pisoni, (2011), Nygaard and Pisoni (1998), and Nygaard et al., (1994), in which participants were asked to transcribe the words they heard. If participants were more willing to guess words they were unsure of when the target voice was familiar, they would report more words overall when the target was familiar, leading to a higher score because a subset (even if only a small, semantically predictable, subset) of these guesses would be correct, whereas not reporting any of those words would always be counted as incorrect. One advantage of the CRM task is that listeners select exactly the same number of words from a fixed list on each trial, meaning that differences in performance between trials containing familiar and unfamiliar voices cannot be explained by a difference in bias (i.e., willingness to guess when uncertain).

Nevertheless, a limitation of the CRM task is that listeners only need to report the color and number key words of the target (e.g., “green six”), rather than every word from the target sentence. Typically, the listener reports what they heard by pressing the correctly coloured digit (e.g., the green “6” button) from a matrix of coloured digits presented on the screen. In the Johnsrude *et al.* (2013) experiment, with only a single masking talker, the listener may have been able to attend to the two colour-number pairs, then retrospectively select the correct coloured digit based on the target callsign voice.

One aim of the current experiment was to determine whether the familiar-target and familiar-masker benefits could be replicated using a different closed-set task that requires participants to report every word in an utterance. We used the sentences of the Boston University Gerald (BUG) corpus (Kidd, Best, & Mason, 2008), which each contain five words (“<Name> <verb> <number> <adjective> <noun>”). The first (Name) word specifies the target sentence and participants report the remaining four words from that sentence. With a two-talker mixture, if they were to attend to the mixture and select the words that matched the callsign voice, they would have to remember eight items (plus keep track of which voice said the target name), which is much more difficult than remembering two colour-number pairs in the CRM task. Given that Johnsrude et al. (2013) found that the magnitude of the familiar-voice benefit depended on the TMR, we presented our stimuli at four different TMRs: -6, -3, 0, and 3 dB.

Another aim of the current study was to examine whether the magnitude of the familiar-voice benefit to intelligibility differs depending on the duration of the relationship. To investigate the length of the relationship, we compared a group of people who heard the voice of their spouse (highly familiar) with a group who heard the voice of a friend (less familiar). In addition, we explored whether within-group differences in relationship duration systematically affect the magnitude of the familiarity benefit. Possibly, the familiar-voice benefit improves gradually with longer durations of knowing someone—and spouses, which are known on average for longer than friends, may provide a greater benefit to intelligibility.

We had a wide age range in the spouse group, so to investigate effects of age, we split the spouse group into older and younger adults. The reason for dividing the spouse group was that older adults have poorer speech comprehension performance than younger adults (Helfer & Freyman, 2008; Tun, O'Kane, & Wingfield, 2002) and this could affect the benefit that listeners get from a familiar voice. Further, we examined whether age affected accuracy differently in each condition. Johnsrude et al. (2013) found that younger participants (aged 44-59 years old) were less likely to report words spoken by a familiar masker voice compared to older participants (aged 60+ years old).

Methods

Participants

Participants were 68 individuals, recruited in pairs. We recruited 16 pairs who were married (16 males, 16 females; "Spouses group") and were aged 28–82 years (median = 59.5

years, interquartile range [IQR] = 33.0). We also recruited 18 pairs of friends (11 males, 25 females; “Friends group”) who were aged 18–25 years (median = 21 years, IQR = 3.5 years). Of these 18 pairs, 11 pairs were friends or roommates, five pairs were romantic couples, and two pairs were siblings. One couple from the spouse group and three pairs from the friend group (including two romantic couples) did not complete the experiment, which required multiple visits. The data from the remaining 60 individuals were analyzed.

We administered a questionnaire that asked about the length of time participants had known each other or had been married. This questionnaire was completed by 30 spouse participants and 15 friend participants. Spouses reported that they had been married for more than 4 years (range 4.1–51.9 years; median = 27.0 years, IQR = 28.8 years). Friend pairs reported that they had known each other for 1.5–19 years (median = 5.0 years, IQR = 16.0 years). An independent samples Mann-Whitney test indicated that the length of time married pairs had been living together was significantly longer than the length of time friend pairs had known each other [$U = 62.00$, $p < .001$].

We split the Spouses group into two groups of approximately equal size based on age: Older (age ≥ 55 years; N = 16) and Younger (age < 55 years; N = 14). This grouping is similar to that used in Johnsrude *et al.* (2013) and allowed us to examine age-related differences in the familiar-target benefit. The age range in the Friends group was substantially smaller, and all were younger than the older Spouses group, so the Friends group was not divided. The sample size of the smallest group (N = 14) is estimated to be sensitive to within-subjects effects of size f = 0.41 with 0.95 power (G*Power Version 3.0.10) (Faul, Erdfelder, Lang, & Buchner, 2007), and therefore should be large enough to detect familiar-voice benefits to intelligibility of the magnitude reported by Johnsrude et al. (2013) (f = 0.72). With 60 participants across the three groups, and 3 familiarity conditions, we should be sensitive to group-by-familiarity interactions of size f = 0.23 with 0.95 power. We are also sensitive to between-subjects effects of size f=.43 with 95% power. (G*Power Version 3.0.10) (Faul, Erdfelder, Lang, & Buchner, 2007).

All participants were self-declared native Canadian English speakers who had no known speech, hearing, or neurological impairments. Participants had hearing levels (measured using pure tone audiometry at four octave frequencies between 500 and 4000 Hz) of 25 dB HL or better averaged across both ears, except for one participant who had an average pure-tone hearing level of 35 dB HL. The same pattern of results obtained whether this individual was included or not, so we report results including data from this participant.

The study was approved by the University of Western Ontario Non-Medical Research Ethics Board. Informed consent was obtained from all participants.

Materials and Procedure

Participants were tested across two or three sessions. During the first session, each participant was recorded while speaking 480 different sentences, taken from the BUG corpus (Kidd et al., 2008). The sentences had the form "<Name> <verb> <number> <adjective> <noun>". In the sub-set used in the experiment, there were two names ('Bob' and 'Pat'), eight verbs, eight numbers, eight adjectives, and eight nouns (see Figure 1). An example is "Bob bought two blue bags". Across the 480 sentences that were recorded, each verb, number, adjective, and noun occurred 60 times. Sentences were recorded at a 44.1 kHz sampling rate using a Sennheiser e845 S microphone connected to a Steinberg UR22 soundcard. Unlike the original BUG corpus, in which each possible word was recorded individually and sentences were later constructed by concatenating individually spoken words, each sentence in this study was recorded in its entirety, thus retaining natural coarticulation and supra-segmental prosody between words. All sentences were normalized to the same root mean square (RMS) amplitude.

Participants returned for the listening task approximately three months (mean days of separation = 74.4 days, standard deviation [SD] = 73.2 days) after completing the recording session. The listening task was completed in either one session of approximately two hours (N = 36) or two sessions of approximately one hour each, which were separated by less than one month (N = 24; mean days of separation = 14.5, SD = 22.8). A post-hoc repeated measures ANOVA with Familiarity (three levels: Familiar Target, Familiar Masker, Both Unfamiliar), TMR (four levels: -6, -3, 0, 3 dB) as within-subjects factors and number of sessions (two levels: 1, 2) as a between-subjects factor revealed that there were no differences in intelligibility between participants who complete the listening task in one session or two sessions, [$F(1, 58)=0.105$, $p=.747$]. Further, there were also no significant interactions with number of sessions ($ps>.075$), indicating that that intelligibility was not affected by the number of testing sessions.

Stimuli were presented diotically through Sennheiser HD265 (N = 26) or Grado Labs SR225 (N = 34) headphones. Each participant heard sentences spoken by three different talkers: the participant's partner (familiar talker), and two other participants in the study who the participant did not know but who were from the same group and were the same sex as the participant's partner (unfamiliar talkers). The two unfamiliar voices remained constant for each participant throughout the experiment.

On each trial, participants heard two different sentences spoken simultaneously by different talkers. All of the words of the two sentences were different. The target sentence was identified by one of two names at sentence onset (either Bob or Pat). One name was used as the target for the first half of trials and the other was used for the second half of trials; the order was counterbalanced across participants. Listeners were instructed to identify the remaining four words in the target sentence by clicking on each word on a computer screen. We matched the occurrences of word combinations, so that participants would not know one word in the sentence based on the presence of other words. As illustrated in Figure 1, the words were arranged in four columns, with one column per word type. Participants selected one word from each column, in any order. The target name (Bob or Pat) was displayed at the top of the screen, as a reminder.

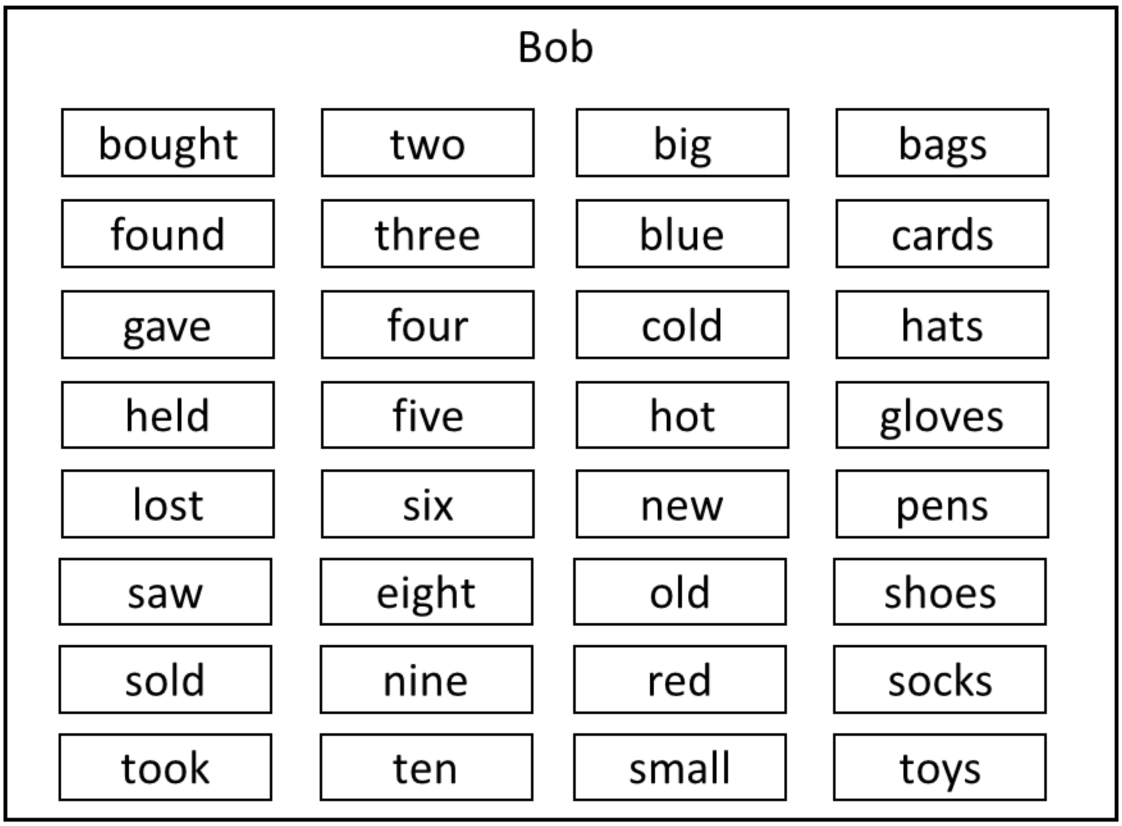

Figure 1. Schematic of the response screen used for the listening task. Participants were asked to choose one word (by a mouse press) from each column according to what they had heard in the target sentence, indicated by the target name (in this example, “Bob”).

Intelligibility of the target sentence was tested in three conditions. In the Familiar Target condition, the target sentence was spoken by the participant's partner (i.e., their familiar voice) and the masker sentence was spoken by one of their two unfamiliar talkers (half with each unfamiliar talker). In the Familiar Masker condition, the masker sentence was spoken by the participant's partner and the target sentence was spoken by one of the unfamiliar talkers (half with each unfamiliar talker). In the Both Unfamiliar condition, the target and masker sentences were spoken by the two unfamiliar talkers. In one half of these trials, one unfamiliar voice was the target and the other was the masker; in the other half, the voice roles were reversed.

We varied the target and masker intensities at four target-to-masker ratios (TMRs): -6, -3, 0, and +3 dB. Acoustic stimuli were presented at a comfortable listening level (approximately 67 dB SPL). The overall amplitude of the target and masker sentences in each trial was roved over a range of 3 dB (in 6 equally spaced levels) to ensure that participants could not use the amplitude of either sentence as a cue to identify the target sentence.

Each participant completed 720 trials: 240 trials in each familiarity condition. Across the experiment, participants heard each of the three voices 240 times as the target and 240 times as the masker. Each familiarity condition contained equal numbers of trials at each of the four TMRs and each of the six rove levels. All trial types were randomly interleaved over 30 blocks of 24 trials each. Participants were prompted to rest, if they wished, between blocks. The participant initiated each block of trials by clicking a prompt on the screen when they were ready to begin.

Analyses

Accuracy

We calculated the proportion of words (out of a possible 960; 4 words in each of 240 trials) that participants reported correctly in each condition. There were 8 options for each word, so the chance level of performance was 12.5%. We used a 3-way mixed analysis of variance (ANOVA) to compare percent correct across Familiarity Conditions (3 levels: Familiar Target, Familiar Masker, Both Unfamiliar, within-subjects), TMRs (4 levels: -6 dB, -3 dB, 0 dB, 3 dB; within-subjects), and groups (3 levels: Young Friends, Young Spouses, and Older Spouses; between-subjects); see Figure 2.

We always presented unfamiliar voices of the same sex as the participant's familiar voice, but because we used natural voices there was some variability across participants in the degree to which the F_0 of the familiar voice differed from that of each of the unfamiliar voices. At the group level, all three familiarity conditions were acoustically very well matched, because all familiar voices also served as unfamiliar voices, meaning that the voices heard as familiar were acoustically identical to those heard as unfamiliar (with the exceptions noted above). However, given that intelligibility of a target talker in the presence of a competing talker is known to improve as the difference in F_0 between the two talkers increases (Assmann, 1999; Darwin, Brungart, & Simpson, 2003; Summers & Leek, 1998), the F_0 difference has the potential to influence intelligibility at an individual level. We therefore included it as a covariate of no interest in the ANOVA.

We estimated the F_0 of each recorded sentence using an in-house script written in Praat (Boersma & Weenink, 2013), which calculated the median F_0 across each sentence at time steps of 0.01 seconds. To determine each talker's F_0, we averaged the median F_0 values across all of the 480 sentences they recorded. For each participant, we calculated the absolute difference in F_0 between the familiar and the average of the two unfamiliar talkers they heard during the experiment. Fundamental frequencies for each sex in each group are described in Table 1 (median = 12.5 Hz, IQR = 20.6 Hz, which corresponds to 2.06 semitones, IQR = 1.70 semitones).

Table 1

Mean fundamental frequency (F_0) in Hz for males and females in each group. Standard deviations are displayed in brackets.

Group	*n*	F_0 (Hz)
Older Spouses		
Male	8	107.69 (16.53)
Female	8	170.76 (10.77)
Younger Spouses		
Male	7	103.73 (12.64)
Female	7	186.95 (22.34)
Young Friends		
Male	7	111.95 (12.84)
Female	23	205.68 (15.84)

Mauchly's tests indicated that the assumption of sphericity was violated for the main effect of Familiarity [$\chi^2(2) = 33.80$, $p < .001$], main effect of TMR [$\chi^2(5) = 89.56$, $p < .001$], and interaction between Familiarity and TMR [$\chi^2(20) = 96.21$, $p < .001$]; these results are reported with Greenhouse-Geisser correction. Pairwise comparisons are reported with Sidak correction for multiple comparisons.

Errors

Incorrectly reported words were categorized as one of two types: (1) 'wrong voice' errors, in which the reported word was from the masker sentence; and (2) 'random' errors, in which the reported word was not contained in either of the two sentences spoken on that trial. Percentage of errors was calculated by dividing the number of each type of error by the total number of words in incorrect trials. We used a four-way mixed multivariate analysis of variance (MANOVA), with average F_0 difference as a covariate of no interest, to compare the percentage of Errors (2 levels: Wrong Voice, Random; within-subjects) across familiarity conditions (3 levels: Familiar Target, Familiar Masker, Both Unfamiliar; within-subjects), TMRs (4 levels: -6, -3, 0, 3 dB; within-subjects), and groups (3 levels: Young Friends, Young Spouses, and Older Spouses; between-subjects). We conducted follow-up within-subjects ANOVAs to better understand the effects of Familiarity and TMR on each type of error (Wrong Voice or Random) separately.

Age-related differences on intelligibility

Johnsrude et al. (2013), using the CRM procedure, observed that task accuracy correlated negatively with age in the Familiar Masker and Both Unfamiliar conditions, but was unrelated to age in the Familiar Target condition. The correlation values differed significantly between the Familiar Target and the other two conditions, and, furthermore, these differences were apparent at TMR values equated across conditions for performance. To examine whether the same relationships obtained in the current matrix-task data, we calculated Spearman correlations between age and accuracy in each of the three familiarity conditions, across the Older and Younger Spouse data. We also statistically compared these correlations (Lee & Preacher, 2013).

Influence of relationship duration

To assess whether the magnitude of the intelligibility benefit gained from a familiar voice is related to the length of the relationship, we conducted a partial correlation between Relationship Duration and Familiar-Target Benefit, calculated as the difference in percent correct between the Familiar Target and Both Unfamiliar conditions for each participant, while controlling for the possibly confounding effect of F_0 difference between familiar and unfamiliar voices. The Relationship Duration was defined for each pair, as the length of time the spouses had been married and the length of time the friends had known each other.

Results

Accuracy

Data are shown in Figure 2. A three-way mixed ANOVA, controlling for the F_0 difference between familiar and unfamiliar voices, revealed no effect of the covariate (F_0 difference), [$F(1, 56) = 0.28$, $p = .60$, $\omega^2 = -.01$] and no significant interactions involving it (*p*s > .05).

The main effect of Familiarity was significant [$F(1.37, 76.76) = 8.40$, $p = .002$, $\omega^2 = .11$]. Participants reported more correct words when the target voice was familiar (Familiar Target: mean = 69.28%, standard error [*SE*] = 2.37) than when the masker voice was familiar (Familiar Masker: mean = 56.97%, SE = 2.23) ($t(59) = 4.81$, $p < .001$), or when both target and masker voice were unfamiliar (Both Unfamiliar: 59.75%, SE = 2.16) ($t(59) = 5.14$, $p < .001$). There was no significant difference in accuracy between the Familiar Masker and Both Unfamiliar conditions ($t(59) = -1.98$, $p = .15$), and the difference trended in the opposite direction to that observed by Johnsrude *et al.* (2013), i.e. towards *worse* target-word report in the Familiar Masker condition.

As expected, there was a significant main effect of TMR [$F(1.49, 83.36) = 19.60$, $p < .001$, $\omega^2 = .24$]. Participants were more accurate at reporting target words at 3 dB TMR (mean = 68.77%, SE = 1.86) than at 0 dB (mean = 62.00%, SE = 1.91) ($t(59) = 8.95$, $p < .001$), -3 dB (mean = 59.26%, SE = 2.01) ($t(59) = 8.86$, $p < .0001$), and -6 dB (mean = 59.94%, SE = 2.26) ($t(59) = 7.60$, $p < .001$). Accuracy was also better at 0 dB than at -3 dB ($t(59) = 4.32$, $p < .001$) and -6 dB ($t(59) = 4.21$, $p = .001$). The percentage of correctly reported words did not differ between -3 dB and -6 dB TMR ($t(59) = 2.10$, $p = .22$).

There was no significant main effect of Group [$F(2, 56) = 1.45$, $p = .24$, $\omega^2 = .02$], suggesting that intelligibility does not differ between older spouses, younger spouses, and friends.

There was a significant interaction between Group and TMR [$F(2.98, 83.36) = 9.78$, $p < .001$, $\omega^2 = .23$]. Performance by older spouses was more affected by TMR than was performance in the other two groups (Figure 2). Intelligibility at higher TMRs (-3, 0, and 3 dB) did not differ between Older and Younger Spouses ($0.03 \geq t(59) \geq 2.34$, ps > .09), but older spouses reported significantly fewer correct words than Younger Spouses at the lowest TMR, -6 dB ($t(59) = -2.74$, $p = .03$).

The interaction between Group and Familiarity was not significant, [$F(2.74, 76.76) = 1.26$, $p = .29$, $\omega^2 = .01$], neither was the three-way interaction between Group, Familiarity, and TMR [$F(6.68, 190.40) = 0.628$, $p = .73$, $\omega^2 = -.01$], suggesting that the presence of a familiar voice affected intelligibility in a similar way across groups and TMRs. None of the other interactions were significant, either ($0.33 \geq t(59) \geq 2.24$, ps > .30).

Despite the absence of an interaction between Familiarity and TMR in the analysis reported above, visual inspection of Figure 2 shows a trend towards worse intelligibility for the Familiar Masker than Both Unfamiliar condition at higher TMRs which is not apparent at better TMRs. We therefore conducted an exploratory post-hoc pairwise comparisons to explore this apparent interaction in more detail. There were two within-subjects variables: Familiarity (two levels: Familiar Masker and Both Unfamiliar) and TMR (four levels: -6, -3, 0, 3 dB). The interaction was significant [$F(2.17,128.20)=3.89$, $p=.02$)]. At the lowest TMRs (-6 and -3 dB), intelligibility did not differ significantly between the Familiar Masker and Both Unfamiliar conditions, $ts(59)\leq1.09$, $ps\geq.28$. However, at higher TMRs (0 and 3 dB), intelligibility was significantly worse in the Familiar Masker than Both Unfamiliar condition ($ts(59)\leq2.57$, $ps=.015$). These results should be interpreted with caution given the interaction was not significant, but they are consistent with a small Familiar Masker intelligibility deficit at the higher TMRs.

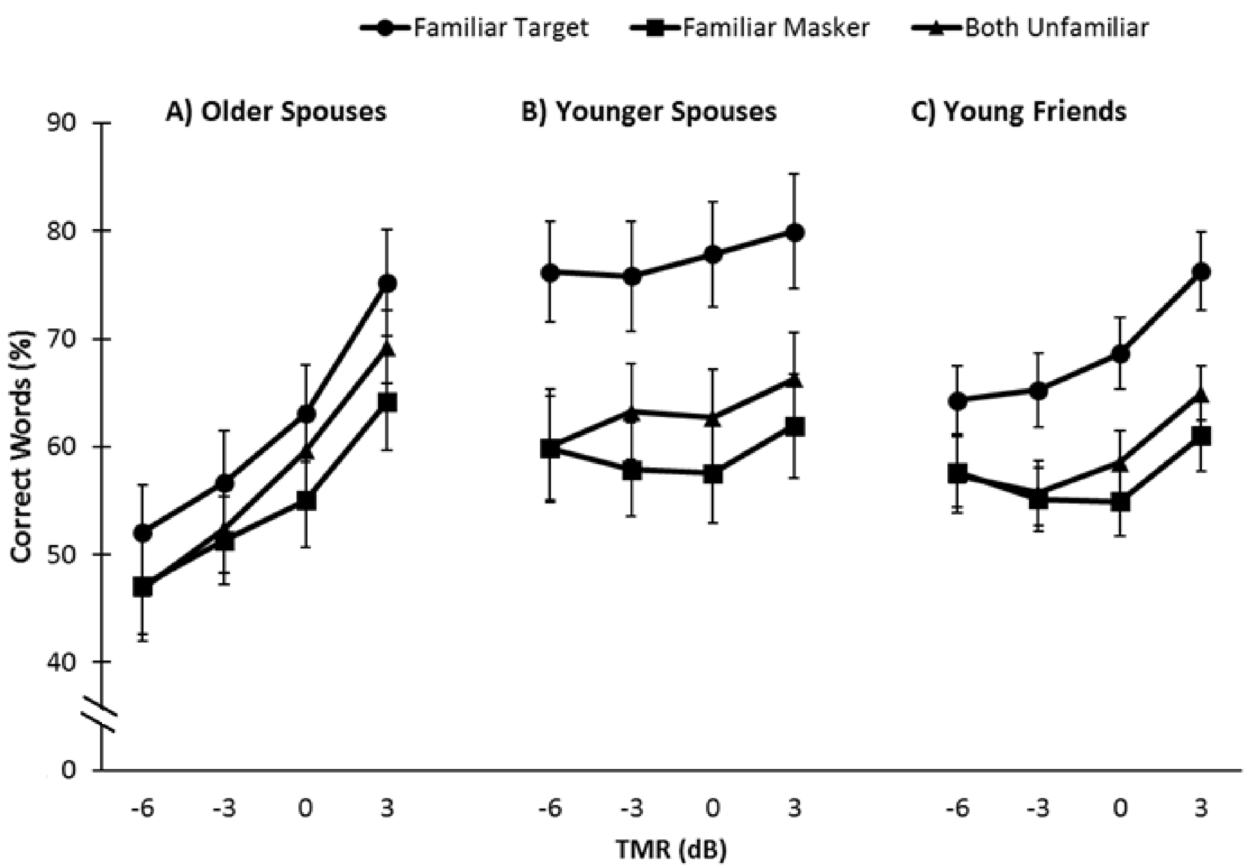

Figure 2. Percentage of correct words in each familiarity condition as a function of target-to-masker ratio (TMR) in in Older Spouses (A), Younger Spouses (B) and Friends (C). Error bars show ±1 standard error of the mean.

We repeated the analyses using the percentage of sentences that were reported correctly (rather than correct words), which we defined as trials in which all four words of the target sentence were reported correctly. For this, chance performance is 0.02%. As expected, the percentage of correct sentences was lower than the percentage of correct words across conditions (Familiar Target: mean = 44.74%, *SE* = 2.58; Familiar Masker: mean = 30.31%, *SE* = 2.47; and Both Unfamiliar: mean = 32.50%, *SE* = 2.12). However, the pattern of results did not differ appreciably from the analysis based on words correct.

As a post-hoc analysis, we checked whether the sibling pairs were driving the results in the Friends group; they may have performed differently since their relationship is of a much longer duration, compared to other pairs in the Friends group. We repeated the accuracy analysis but excluded the two sibling pairs, and results did not differ from those reported above. We conducted a separate repeated-measures ANOVA on the Friends group (with siblings excluded) to determine whether there were accuracy differences between friends (n=22) and dating couples (n=10) across Familiarity conditions and TMRs. We did not find any effect of relationship type [$F(1, 23) = 1.84$, $p = .19$, $\omega^2 = .03$].

Errors

In general, people made substantially more 'wrong voice' than 'random' errors. Among the identified words in error trials (those in which at least one word out of a possible four was identified incorrectly), 48.59% (SE = .82) were wrong voice errors, and 10.10% (SE = .56) were random errors. The remaining 41.31% were correctly identified words. The data are presented in Figure 3.

We conducted a four-way mixed MANOVA to compare the proportion of these two types of error across Familiarity Conditions, Groups, and TMR, while controlling for F_0 differences between familiar and unfamiliar voices. The effect of the covariate was not significant, [$F(1, 56) = .559$, $p = .46$, $\omega^2 = -.01$], nor were any of the interactions involving it (*p*s > .15). We only report the main effect of the Error Type factor and interactions involving it, since the other effects are similar to those reported in the Accuracy analysis (above).

The analysis confirmed that the main effect of Error Type was significant [$F(1, 56) = 374.87$, $p < .001$, $\omega^2 = .87$]. The interaction between Group and Error Type was also significant [$F(2, 56) = 4.43$, $p = .02$, $\omega^2 = .10$]. Whereas the proportion of wrong voice errors did not differ among the three Groups (1.63 ≥ t(59) ≥ 2.17, *p*s > .10), Older Spouses made more random errors than did Younger Spouses (t(59) ≥ 2.51, *p* = .045) and Friends (t(59) ≥ 3.67, *p* = .01). The proportion of random errors did not differ between Younger Spouses and Friends (t(59) ≥ 0.67, *p* = .88).

The interaction between Error Type and Familiarity condition trended towards significance [$F(2, 55) = 2.80$, $p = .07$, $\omega^2 = .06$]. Given that we were expecting to find a difference between the familiar-masker and both-unfamiliar conditions (based on Johnsrude et al., 2013), we explored this interaction further. Although the proportion of Random errors did not differ across familiarity conditions (0.43 ≥ t(59) ≥ 1.61, *p*s > .30), participants made significantly fewer Wrong Voice errors in the familiar-target compared to the familiar-masker and both-unfamiliar conditions (-4.99 ≥ t(59) ≥ -3.58, *p*s < .01). The percentage of Wrong Voice errors did not differ between the familiar-masker and both-unfamiliar conditions (t(59) = 0.36, *p* = .98).

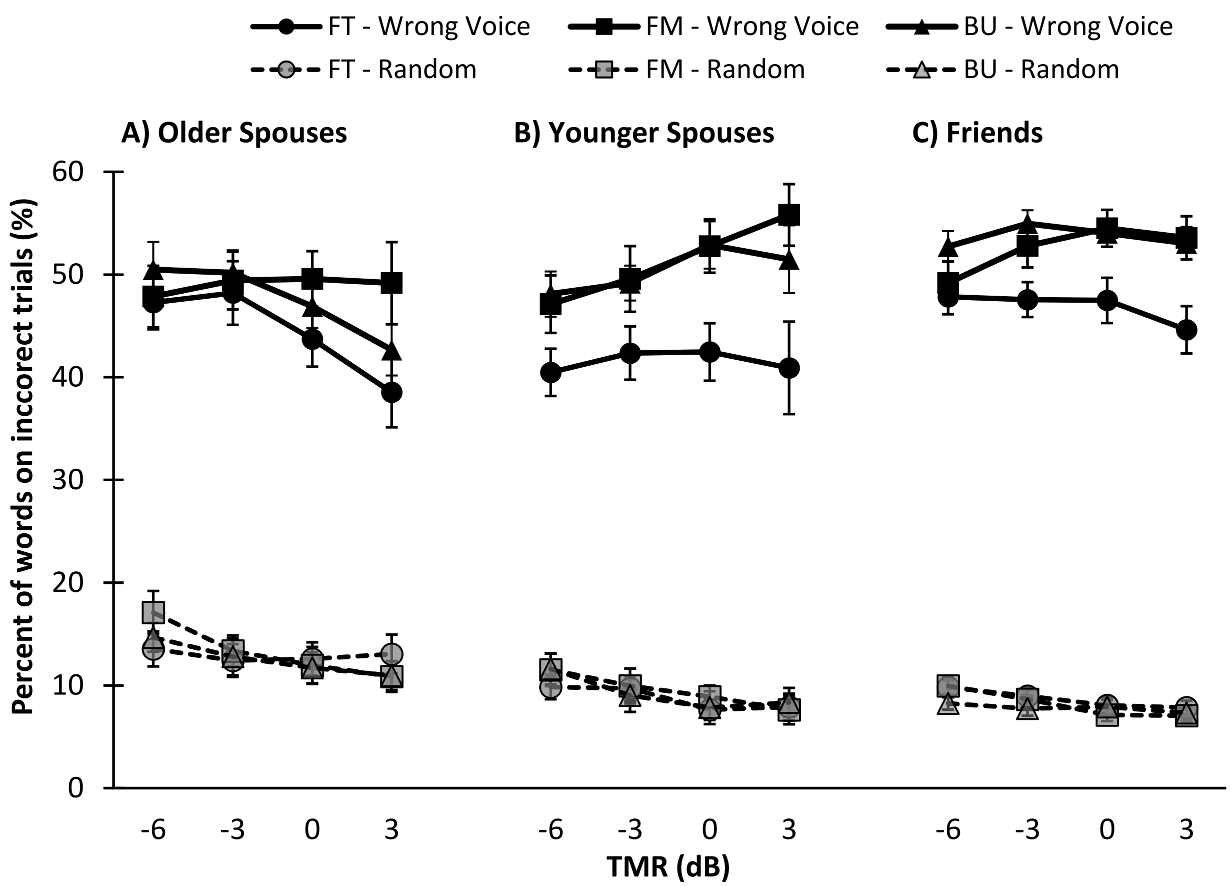

Figure 3. Error analysis. 'Wrong voice' errors (black markers, solid lines), and 'random' errors (grey markers, dashed lines) in incorrect trials as a function of target-to-masker ratio (TMR), expressed as a proportion of all words presented on incorrect trials (trials on which at least one word was reported incorrectly). Left panel (A) shows data from Older Spouses, middle panel (B) shows data from Younger Spouses, and right panel (C) shows data from Friends. Error bars show ±1 standard error of the mean (SE). FT (circles): Familiar Target; FM (squares): Familiar Masker; BU (triangles): Both Unfamiliar.

Age-related differences on intelligibility

There was a significant negative correlation between age and accuracy in the Familiar Target condition (collapsed across TMRs) [r_s = -.51, p = .004], but not in the Familiar Masker condition [r_s = -.07, p = .70], or in the Both Unfamiliar condition [r_s = -.31, p = .09]. These correlations are shown in Figure 4. We tested for any differences between these correlations (Lee & Preacher, 2013). Correlations in the familiar-target and familiar-masker conditions differed significantly from each other [Z = -.208, p = .037], whereas correlations in the familiar-target condition did not differ significantly from the correlation in the both-unfamiliar condition [Z = -1.08, p = .28]. These results suggest that Familiar-Target intelligibility decreases more rapidly with age compared to Familiar Masker intelligibility but not more rapidly than Both Unfamiliar intelligibility.

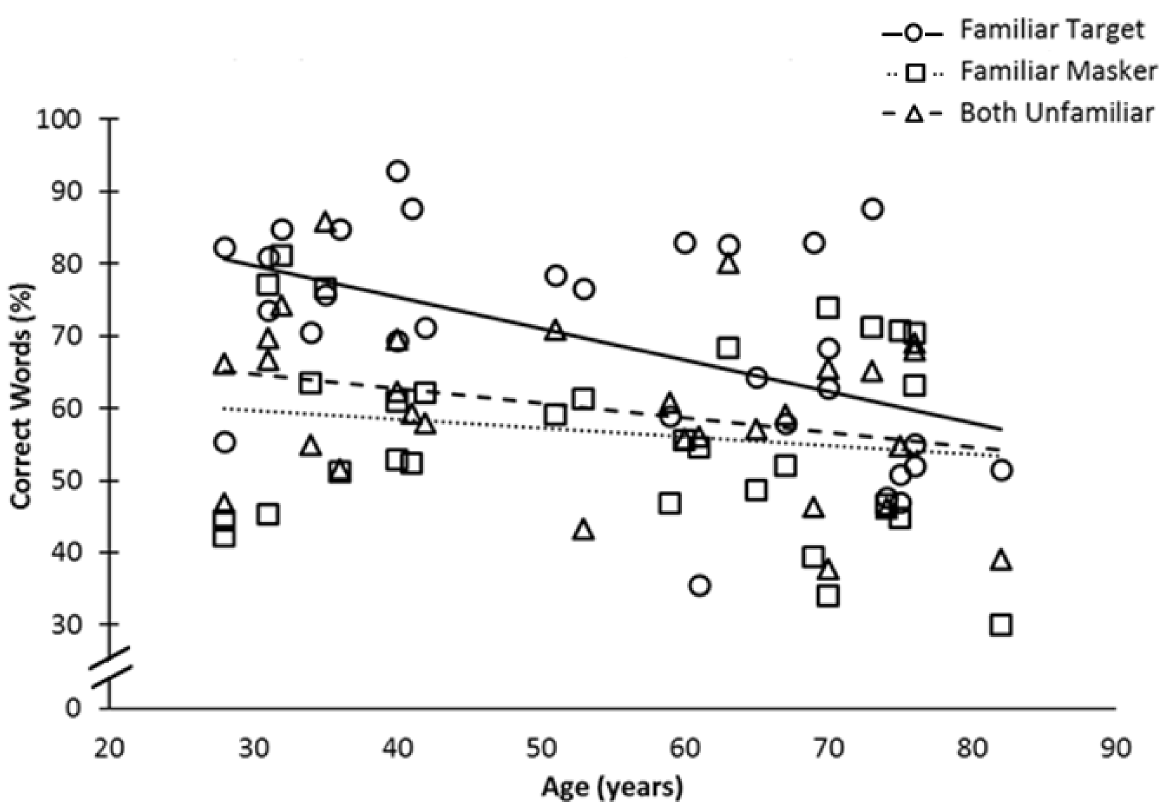

Figure 4. Scatter plot and best-fit regression lines showing the relationship between age and accuracy in the Familiar Target (circles, solid line), Familiar Masker (squares, dotted line), and Both Unfamiliar (triangles, dashed line) conditions.

Influence of relationship duration

Despite finding no significant differences in the familiar-voice benefit between the Spouses and Friends groups (which would have manifest as a significant interaction between Group and Familiarity Condition in the analyses above), we wanted to examine whether variability in length of time participants had known their partner related to the magnitude of the familiar-voice benefit. We tested the partial correlation between Relationship Duration and the familiar-target benefit (difference in intelligibility between the Familiar Target and Both Unfamiliar conditions) across individuals, while controlling for the F_0 difference between the familiar and unfamiliar voices. The correlation was not significant [$r = -.24$, $p = .12$] in the range we had questionnaire data for (1.5-51.9 years). This result suggests that longer relationships do not systematically increase the benefit to intelligibility from a familiar voice.

Influence of talker F_0

In addition to including F_0 as a covariate in our main analysis (above), we also tested post-hoc whether larger F_0 differences were related to bigger apparent familiar-voice intelligibility benefits at an individual level (as we might expect). A Shapiro-Wilk's test indicated that F_0 differences differed significantly from a normal distribution, [$W(60) = .917$, $p = .001$]; therefore we conducted a Spearman's correlation between the F_0 difference and the individual intelligibility benefit across participants. For this correlation analysis, we analyzed all participants in one group (spouses and friends combined) so that we had more power to detect a significant relationship.

There was a significant positive correlation between the magnitude of the difference in intelligibility and the magnitude of the F_0 difference between the familiar and the two unfamiliar talkers (averaged together) [$r_s = .26$, $p = .045$]. This result demonstrates that the F_0 difference between the familiar and unfamiliar voices explained a significant amount of the individual variability in the magnitude of the familiar-target benefit, as expected.

Influence of sex of familiar voice

Given the unfamiliar voices were sex-matched to the familiar voice, we conducted another post-hoc analysis to determine whether the sex of the familiar voice had an effect of on intelligibility. We conducted a mixed ANOVA with Familiarity (Familiar Target, Familiar Masker, Both Unfamiliar) and TMR (-6, -3, 0, 3 dB) as within-subjects factors and sex of the familiar talker as a between-subjects factor.

There was no effect of the sex of the familiar talker, [$F(1,58) = .001$, $p=.98$, $\omega^2 = -.002$], or any significant interactions involving it (ps $\geq .38$), suggesting that presenting mixtures of male voices or female voices did not affect intelligibility. We therefore collapsed across sex for the remainder of the analyses.

Do unfamiliar voices become ‘familiar’?

Participants heard the two unfamiliar voices many times throughout the experiment, and it is possible that these unfamiliar voices became ‘familiar’ by the end of the experiment. Adaptation to new forms of speech has been shown to occur rapidly, after only 15 trials of exposure (Davis et al, 2005; Huyck & Johnsrude, 2012). Therefore, we conducted a post-hoc analysis to determine whether participants became familiar with the two unfamiliar voices, which would manifest as a greater improvement in intelligibility scores for unfamiliar-target than familiar-target conditions from the beginning of the experiment to the end. Separately for the three Familiarity Conditions, we took a subset of 20 trials from the beginning and end of the experiment, which should be sufficient to get a stable average whilst also being sensitive to perceptual learning of unfamiliar voices of the type described by Huyck and Johnsrude (2012).

We conducted a three-way repeated measures ANOVA to compare the percent of words reported correctly across Groups (3 levels: Older Spouses, Younger Spouses, and Friends), Familiarity conditions (3 levels: Familiar Target, Familiar Masker, Both Unfamiliar) and Trial Positions (2 levels: first and last 20 trials). If, following exposure to the voices, unfamiliar voices became similar to familiar voices, there should be a Familiarity Condition by Trial Position interaction such that accuracy in Both Unfamiliar trials improves to a greater extent between the first and last 20 trials than does accuracy in the Familiar Target condition.

Figure 5 illustrates percent correct in the first and last 20 trials for all three conditions, collapsed across groups. There was a significant effect of Trial Position [$F(1, 57) = 89.05$, $p < .001$, $\omega^2 = .60$]: the last 20 trials (mean: 63.47%, *SE* = 1.25) were more intelligible than the first 20 trials (mean = 52.68%, *SE* = 1.29).

Importantly, there was no significant interaction between Familiarity condition and Trial Position [$F(1.35, 76.78) = 1.05$, $p = .33$, $\omega^2 = .00$], but intelligibility of unfamiliar voices did not improve to a greater extent than did intelligibility of familiar voices. Thus, we found no evidence that intelligibility of the unfamiliar voices was enhanced by learning over the experiment. There was no significant 2-way interaction between Group and Trial Position [$F(2, 57) = 0.97$, $p = .37$, $\omega^2 = .00$] and no significant 3-way interaction between Group, Trial Position, and Familiarity [$F(2.69, 76.78) = 0.60$, $p = .60$, $\omega^2 = -.01$]. Thus, the magnitude of the improvement in intelligibility between the first and last 20 trials did not differ among groups. Because we assume that the perceptual learning of the familiar voice has occurred before the experiment and has reached its maximum (as participant pairs are required to know each other for at least six months and speak regularly), we interpret the overall improvement in performance between the first 20 and last 20 trials as attributable to practice effects.

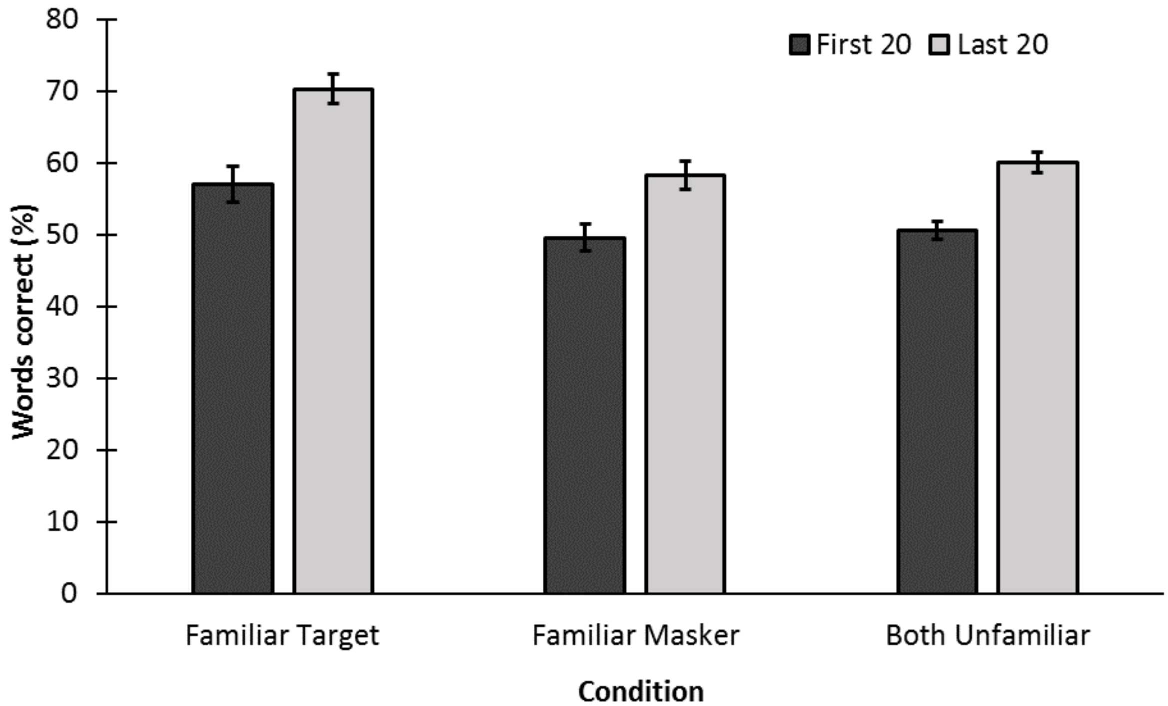

Figure 5. Percent correct of first and last 20 trials, collapsed over Groups and TMRs, for each condition. Error bars represent ±1 standard error of the mean.

Discussion

Familiar-target benefit is similar for spouses and friends

Our results demonstrate that people are better at understanding speech in the presence of a competing talker when the talker they are listening to is a spouse or friend, compared to when it is someone unfamiliar. Words spoken in a familiar voice (Familiar Target condition) were, on average, 10–15% more intelligible than words spoken in an unfamiliar voice (Familiar Masker and Both Unfamiliar conditions; Figure 2). Thus, we replicate the familiar-target benefit found in previous experiments (Gass & Varonis, 1984; Johnsrude et al., 2013; Kreitewolf et al., 2017;

Newman & Evers, 2007; Nygaard et al., 1994; Souza et al., 2013; Yonan & Sommers, 2000) using the closed-set BUG task. Furthermore, we show that friend's voices and spouse's voices appear to be similarly beneficial for intelligibility when a competing talker is present.

Our results extend previous findings by demonstrating a familiar-target benefit for a closed-set test with a high memory load (BUG corpus; Kidd, Best, & Mason, 2008). In contrast, previous experiments used either open-set tests (Newman & Evers, 2007; Yonan & Sommers, 2000) or closed-set tests with a low memory load (i.e., the CRM test in Johnsrude et al., 2013). That the familiar-voice benefit is present for closed-set tests indicates that it is not (entirely) due to systematic differences in response bias when people hear speech in familiar and unfamiliar voices: Unlike open-set tasks using naturalistic stimuli, participants reported a fixed number of words on every trial, and the words could never be predicted based on the previous word(s). Therefore, participants must guess if unsure on every trial, regardless of whether they heard a familiar or unfamiliar voice. The high memory load of the BUG task is more similar to everyday conversations than the CRM task used by Johnsrude et al. (2013); in most everyday situations, successful communication requires listeners to follow all or most of the words spoken by an interlocutor, whereas the CRM task only requires listeners to extract the colour-number coordinate near the end of each sentence. The current results increase our confidence that the familiar-voice benefit improves speech intelligibility in natural communication settings.

The familiar-target benefit we found is similar in magnitude to that reported in previous studies (Johnsrude et al., 2013) using closed-set testing that controls for the effect of guessing (bias) on measured intelligibility. Johnsrude *et al.* (2013) found a 10–15% improvement in intelligibility (sentence report) when a target sentence was spoken by the participant's spouse than when it was spoken by an unfamiliar talker. Here, we found no evidence for a difference in the magnitude of the benefit for spouses and friends. Spouses generally knew each other for longer than the friends we tested and presumably have relationships that differ in quality from those of the friend pairs. Nevertheless, the intelligibility benefit appeared similar for friends and spouses. Consistent with this result, we found no correlation between the length of time participants had known each other and the magnitude of the intelligibility benefit. Given these results**,** it is possible that intelligibility due to familiarity with someone's voice manifests rather quickly (within 1.5 years of knowing someone) and then remains stable in magnitude as the relationship extends through the years.

Our finding that the benefit to intelligibility of friends' voices is as robust as the benefit from a spouse's voice when heard in the presence of a competing talker, has practical significance. To the extent that our results generalize to real-world listening, the intelligibility of casual friends in busy environments should be as high as the intelligibility of a longstanding life partner. People do not need to be exposed to a voice as intensively as they have been exposed to their spouse's voice to improve intelligibility substantially. That familiar voices can improve intelligibility after relatively short exposure is consistent with the results of Newman and Evers (2007), who showed that participants were better at understanding words spoken by a psychology professor by whom they had been taught for one semester than words spoken by a novel voice. In addition, training studies have shown a familiar-voice benefit when participants are exposed to voices for as little as six hours (Kreitewolf et al., 2017). However, the benefit of a lab trained voice appears to be of smaller magnitude compared to the benefits we have observed (approximately 10-15%, which we estimate was equivalent to ≥ 3 dB for all groups): 0.52 dB in Kreitewolf, Mathias, & von Kriegstein (2017)**,** approximately 5-10% (Nygaard et al., 1994)**,** and approximately 3-15% (Nygaard & Pisoni, 1998). Furthermore, given the impoverished materials that we used, and the lack of natural prosodic and contextual information, we think this measured benefit probably underestimates real-world benefit.

Intelligibility of the unfamiliar voices did not approach the intelligibility of familiar voices by the end of our experiment, demonstrating that more than brief, incidental, exposure to voices is required to produce a familiar-target benefit of the magnitude observed here. This finding arose despite participants hearing unfamiliar voices more in the experiment than familiar voices (because two unfamiliar voices and one familiar voice were presented to each participant). A longitudinal study could investigate the time course of the familiar-voice benefit in more detail, and determine what type of experience with a voice is required for an intelligibility benefit to be observed. If a trained talker who the participant has never met could provide an intelligibility benefit as large as that found here, then voice training could have great potential for improving intelligibility in everyday environments—such as public announcements in busy places—and these might help people who find it difficult to listen in noise, including older people who experience declines in hearing with healthy aging. In either case, our results suggest that older spouses gain as much benefit from a familiar voice as younger spouses and younger friends, suggesting that real-world speech intelligibility can be improved by voice familiarity.

No benefit of familiarity with a masker voice

In contrast to Johnsrude *et al.* (2013), we found no benefit of familiarity with the masker voice on the intelligibility of an unfamiliar target voice in any of the three groups. To our knowledge, Johnsrude *et al.* (2013) is the only study to have found a familiar-masker benefit. Johnsrude *et al.* (2013) concluded that the presence of a familiar voice in a mixture (as either the target or masking voice) may aid in perceptual organization. If they had found no familiar-masker benefit, and only a benefit when the familiar voice is the target (and focus of attention), this result could have been accounted for by a template-matching strategy in which participants use a mental representation of the familiar voice to extract it from the mixture (Bregman, 1990). By definition, this strategy is only possible when the speech matching the template is the focus of attention, and therefore cannot explain the familiar-masker benefit they observed.

The absence of a familiar-masker benefit in this study compared to Johnsrude *et al.* (2013) could be due to the greater cognitive demand of the BUG task compared to the CRM task. The BUG and CRM materials that were used here and in Johnsrude *et al.* (2013) are both closed-set matrix tests, but differ markedly on the number of items to be reported (four words in BUG and one colour-number pair in CRM). To respond correctly in our BUG task, participants would have to identify the target voice (specified by the 'name' word) and correctly report the other four words ('verb' 'number' 'adjective' 'noun') in the target sentence. To respond correctly on Familiar Target or Familiar Masker trials in the CRM task, participants need only attend to the call sign at the onset, decide whether their partner's voice is the target (i.e., said 'Baron') or the masker, register both coloured digits, then retrospectively indicate the one spoken by their partner (if target) or the other talker (if their partner is the masker). This strategy is a lot harder to deploy if eight to ten unrelated words have to be held in memory and each assigned to the correct voice. The difference in strategies that could possibly be used for the CRM and BUG tasks could explain why Johnsrude *et al.* (2013) found better overall intelligibility than we found in the current experiment, and why they observed a familiar-masker benefit and we did not.

Our results, if anything, instead show a trend towards a Familiar Masker deficit. This deficit looks like the reverse of the Familiar Masker advantage reported by Johnsrude et al. (2013) in that the deficit was greater at higher TMRs. Possibly, familiar voices in the current study were more distracting when they were more intelligible (i.e., at higher TMRs), which would be consistent with the findings of Kreitewolf et al. (2018) who showed that memory for target speech was worse when a to-be-ignored voice was familiar. Nevertheless, the Familiar Masker deficit in the current study was not robust—there was no significant difference between the Both Unfamiliar and Familiar Masker conditions when all TMRs were included in the analysis, and the interaction between TMR and Familiarity was not significant when Familiar Target data were also included. Clearly, further research is needed to elucidate the effects of a familiar masker voice and the conditions under which it improves or impairs the intelligibility of target speech.

Older spouses

The pattern of performance in older spouses (55–82 years) was somewhat different to that in younger listeners. Although the groups did not differ in overall intelligibility, performance in the older spouse group was more dependent on TMR (Figure 2) and accuracy in the Familiar Target condition decreased as age increased (Figure 4). The absence of intelligibility differences between groups that were observed may be due to a lack of power. Any group differences, if they indeed exist, would likely have an effect size smaller than what we were sensitive to in the current study (f=.43).

Older spouses also made significantly more ‘random’ errors (i.e., words not presented in either the target or masker sentences) than did younger spouses and friends. Both the larger influence of TMR on intelligibility, and increased proportion of ‘random’ errors, is consistent with greater energetic masking in this group, which could result from subclinical hearing loss (i.e., in the absence of shifts in audiometric thresholds) that is related to age—for example, due to broader filter widths (see Badri, Siegel, & Wright, 2011). These results could also be due to age-related attentional decline (Alain & Woods, 1999; Godefroy, Roussel, Despretz, Quaglino, & Boucart, 2010), exacerbated by more challenging listening conditions (i.e., lower TMRs).

Regardless of the mechanism, our results suggest that older spouses gain as much benefit from a familiar voice as younger spouses and friends, suggesting that real-world speech intelligibility can be improved by voice familiarity. Familiarity with a voice, which could be gained by speaking to a friend in quiet settings, might help to protect against social isolation in older adults, which has been linked to increased risk of depression (Carabellese et al., 1993) and dementia (Lin et al., 2013).

Effect of magnitude of difference in F_0 within listeners

As expected, listeners gained a larger intelligibility benefit from a familiar voice (compared to unfamiliar voices) if the F_0 difference between the familiar voice and unfamiliar voices was larger, demonstrating a well-established effect of acoustics on speech intelligibility (Assmann, 1999; Darwin, Brungart, & Simpson, 2003; Summers & Leek, 1998). Our counterbalancing of voices ensured that, at the group level, the voices in the Familiar Target condition were the same as those in the Familiar Masker condition and in the Both Unfamiliar condition. The voices in each condition were identical in the spouse groups, but because of the six participants who dropped out of Friends group, the voices in each condition were slightly different. Those six voices only served as unfamiliar, and three other voices only served as familiar. Nevertheless, analyses of the familiar-voice benefit also covaried for the F_0 difference between familiar and unfamiliar voices. The finding of a significant familiar-target benefit, even after factoring out influences of the F_0 difference, indicates that familiarity with a voice (as well as acoustic similiarity between it and a competing unfamiliar voice) contributes to its intelligibility.

Masker words less likely to be mistaken for target words in the familiar-target condition

‘Wrong voice’ errors—in which the response was from the masker sentence—occurred considerably more frequently than ‘random’ errors. Whereas ‘random’ errors probably arise because listeners were not able to hear words from the target (energetic masking; Brungart, 2001; Brungart et al., 2001; Durlach, 2006), ‘wrong voice’ errors mean that the listener could hear at least part of the target-masker mixture adequately, but they reported a word spoken by the masker voice. This type of error may reflect one of several underlying issues; for example, a difficulty segregating the two speech streams, extracting a target signal from a mixture which becomes more challenging at low TMRs, selectively attending to the target, or potentially some other difficulty that would fall under the umbrella of ‘informational masking’ (Durlach, Mason, Kidd, et al., 2003; Durlach, Mason, Shinn-Cunningham, et al., 2003; Kidd et al., 2007). Fewer ‘wrong voice’ errors were made in the Familiar Target condition than in the other two conditions. This demonstration of less interference by the masker in the familiar-target condition is effectively a ‘release from informational masking’ and recent work suggests that it may result because speech spoken by a familiar talker is more resistant to interference from maskers that are linguistically similar to the target (Holmes & Johnsrude, 2019). The Familiarity condition and Group factors did not interact, suggesting that familiar voices reduced informational masking—or, more specifically, interference from the masker—to a similar extent for spouses’ and friends’ voices, and for older and younger people.

No evidence for improved familiarity with previously unfamiliar voices

In all three groups, performance in all of the familiarity conditions improved by a similar magnitude between the start and end of the experiment. We attribute this improvement to task-specific learning (e.g., practice effects). Given that participants were already highly familiar with their friend’s or spouse’s voice before the experiment began, we expected any learning of unfamiliar voices to manifest as a greater improvement for the unfamiliar than familiar voices between the beginning and end of the experiment. Previous studies have shown that voice training (Kreitewolf et al., 2017; Nygaard & Pisoni, 1998; Nygaard et al., 1994) or brief prior exposure to a voice (e.g., Brungart et al., 2001) can improve intelligibility. However, the incidental exposure provided here did not appear to be sufficient to provide talker-specific learning for the unfamiliar voices.

Conclusions and Implications

Prior experience with a voice leads to a considerable improvement in intelligibility when that voice is heard in the presence of competing sounds. We found no evidence that the magnitude of the familiar-voice benefit differed between friends and spouses. This result implies that intelligibility of speech spoken by a familiar person has already reached a plateau after we have known someone as a friend for 1.5–19 years and stays constant despite many more years of exposure to their voice (up to 52 years of marriage). Our work, using a restricted set of words and controlling for variability in speech production, probably underestimates the benefit derivable in real listening conditions when conversing with a friend or partner. Yet, even under these controlled conditions in which listeners must utilize knowledge of voice acoustics to improve intelligibility, the intelligibility benefit gained from hearing a familiar voice as the target is large (10–20%) and is robust across different tasks (BUG and CRM) and across different types of relationship (friends and spouses). These results highlight the robustness of voice familiarity as a cue to enhance intelligibility.

References

Alain, C., & Woods, D. L. (1999). Age-related changes in processing auditory stimuli during visual attention: Evidence for deficits in inhibitory control and sensory memory. *Psychology and Aging, 14*, 507-519. doi: 10.1037/0882-7974.14.3.507

Assmann, P. F. (1999). Fundamental frequency and the intelligibility of competing voices. In *Proceedings of the 14th International Congress of Phonetic Sciences* (pp. 179–182). San Francisco.

Best, V., Thompson, E. R., Mason, C. R., & Kidd, G. (2013). An Energetic Limit on Spatial Release from Masking. *Journal of the Association for Research on Otolaryngology*, *14*(4), 603–610. https://doi.org/10.1007/s10162-013-0392-1

Bolia, R. S., Nelson, W. T., Ericson, M. A., & Simpson, B. D. (2000). A speech corpus for multitalker communications research. *The Journal of the Acoustical Society of America*, *107*(2), 1065–1066. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10687719

Bregman, A. S. (1990). Auditory Scene Analysis. *The Perceptual Organization of Sound*. Retrieved from http://ci.nii.ac.jp/naid/10004964894/en/

Brungart, D. S. (2001). Informational and energetic masking effects in the perception of two simultaneous talkers. *The Journal of the Acoustical Society of America*, *109*(3), 1101. https://doi.org/10.1121/1.1345696

Brungart, D. S., Simpson, B. D., Ericson, M. A., & Scott, K. R. (2001). Informational and energetic masking effects in the perception of multiple simultaneous talkers. *The Journal of the Acoustical Society of America*, *110*(5), 2527–2538. https://doi.org/10.1121/1.1408946

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *The Journal of the Acoustic Society of America*, *25*(5), 1262–2527.

https://doi.org/10.1121/1.1408946

Darwin, C. J., Brungart, D. S., & Simpson, B. D. (2003). Effects of fundamental frequency and vocal-tract length changes on attention to one of two simultaneous talkers. *The Journal of the Acoustical Society of America*, *114*(5), 2913–2922. https://doi.org/10.1121/1.1616924

Dubno, J. R., Dirks, D. D., & Morgan, D. E. (1984). Effects of age and mild hearing loss on speech recognition in noise. *The Journal of the Acoustical Society of America*, *76*(1), 87–96. Retrieved from http://asadl.org/jasa/resource/1/jasman/v76/i1/p87_s1

Durlach, N. (2006). Auditory masking: Need for improved conceptual structure. *The Journal of the Acoustical Society of America*, *120*(4), 1787–1790. https://doi.org/10.1121/1.2335426

Durlach, N. I., Mason, C. R., Kidd, G., Arbogast, T. L., Colburn, H. S., & Shinn-Cunningham, B. G. (2003). Note on informational masking (L). *The Journal of the Acoustical Society of America*, *113*(6), 2984–2987. https://doi.org/10.1121/1.1570435

Durlach, N. I., Mason, C. R., Shinn-Cunningham, B. G., Arbogast, T. L., Colburn, H. S., & Kidd, G. (2003). Informational masking: Counteracting the effects of stimulus uncertainty by decreasing target-masker similarity. *The Journal of the Acoustical Society of America*, *114*(1), 368. https://doi.org/10.1121/1.1577562

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191.

Gass, S., & Varonis, E. M. (1984). The effect of familiarity on the comprehensibility of nonnative speech. *Language Learning*, *34*(1), 65–87.

Glyde, H., Buchholz, J. M., Nielsen, L., Best, V., Dillon, H., Cameron, S., & Hickson, L. (2015). Effect of audibility on spatial release from speech-on-speech masking. *The Journal of the*

Acoustical Society of America, *138*(5), 3311–3319. https://doi.org/10.1121/1.4934732

Helfer, K. S., & Freyman, R. L. (2008). Aging and speech-on-speech masking. *Ear and Hearing*, *29*(1), 87–98. https://doi.org/10.1097/AUD.0b013e31815d638b.Aging

Johnsrude, I. S., Mackey, A., Hakyemez, H., Alexander, E., Trang, H. P., & Carlyon, R. P. (2013). Swinging at a cocktail party: voice familiarity aids speech perception in the presence of a competing voice. *Psychological Science*, *24*(10), 1995–2004. https://doi.org/10.1177/0956797613482467

Kidd, G., Best, V., & Mason, C. R. (2008). Listening to every other word: examining the strength of linkage variables in forming streams of speech. *The Journal of the Acoustical Society of America*, *124*(6), 3793–3802. https://doi.org/10.1121/1.2998980

Kidd, G. J., Mason, C. R., Richards, V. M., Gallun, F. J., & Durlach, N. I. (2007). Informational Masking. In W. A. Yost & R. R. Fay (Eds.), *Auditory Perception of Sound Sources* (pp. 143–190). Springer.

Kitterick, P. T., Bailey, P. J., & Summerfield, A. Q. (2010). Benefits of knowing who, where, and when in multi-talker listening. *The Journal of the Acoustical Society of America*, *127*(4), 2498–2508. https://doi.org/10.1121/1.3327507

Kreitewolf, J., Mathias, S. R., & von Kriegstein, K. (2017). Implicit talker training improves comprehension of auditory speech in noise. *Frontiers in Psychology*, *8*, 1584. https://doi.org/10.3389/fpsyg.2017.01584

Lee, I. A., & Preacher, K. J. (2013). Calculation for the test of the difference between two dependent correlations with one variable in common [Computer Software]. *Computer Software*. https://doi.org/http://quantpsy.org/corrtest/corrtest2.htm

Levi, S. V, Winters, S. J., & Pisoni, D. B. (2011). Effects of cross-language voice training on speech perception: whose familiar voices are more intelligible? *The Journal of the Acoustical Society of America*, *130*(6), 4053–4062. https://doi.org/10.1121/1.3651816

Mesgarani, N., & Chang, E. F. (2012). Selective cortical representation of attended speaker in multi-talker speech perception. *Nature*, *485*(7397), 233–236. https://doi.org/10.1038/nature11020

Newman, R. S., & Evers, S. (2007). The effect of talker familiarity on stream segregation. *Journal of Phonetics*, *35*(1), 85–103. https://doi.org/10.1016/j.wocn.2005.10.004

Nygaard, L. C., & Pisoni, D. B. (1998). Talker-specific learning in speech perception. *Perception & Psychophysics*, *60*(3), 355–376. https://doi.org/10.3758/BF03206860

Nygaard, L. C., Sommers, M. S., & Pisoni, D. B. (1994). Speech perception as a talker-contingent process. *Psychological Science*, *5*(I), 42–46.

Souza, P. E., Gehani, N., Wright, R., & McCloy, D. (2013). The advantage of knowing the talker. *Journal of the American Academy of Audiology*, *24*(January 2013), 689–700. https://doi.org/10.3766/jaaa.24.8.6

Summers, V., & Leek, M. (1998). F0 processing and the seperation of competing speech signals by listeners with normal hearing and with hearing loss. *Journal of Speech, Language, and Hearing Research*, *41*(6), 1294–1306. https://doi.org/10.1044/jslhr.4106.1294

Tun, P. a, O'Kane, G., & Wingfield, A. (2002). Distraction by competing speech in young and older adult listeners. *Psychology and Aging*, *17*(3), 453–467. https://doi.org/10.1037/0882-7974.17.3.453

Van Engen, K., & Bradlow, A. (2007). Sentence recognition in native-and foreign-language multi-talker background noise. *The Journal of the Acoustical Society of America*, *121*(1), 519–526.

Van Lancker, D. R., & Kreiman, J. (1987). Voice discrimination and recognition are separate abilities. *Neuropsychologia*, *25*(5), 829–834. https://doi.org/10.1016/0028-3932(87)90120-5

Yonan, C. A., & Sommers, M. S. (2000). The effects of talker familiarity on spoken word identification in younger and older listeners. *Psychology and Aging*, *15*(I), 88–99. https://doi.org/10.1037/0882-7974.15.1.88