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Gradient Effects of Reading Ability on Native and Non-Native Talker Identification

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Gradient Effects of Reading Ability on Native and Non-Native Talker Identification

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Table of Contents

Abstract

The acoustic signal of speech cues information about who is speaking in addition to a talker's conceptual message. Recent findings indicate that these two aspects of the acoustic signal are fundamentally intertwined in the context of speech perception. For example, listeners demonstrate a native-language advantage for talker identification, which has been interpreted as evidence that phonological knowledge is recruited for talker identification. Converging evidence for this account comes from studies indicating adults with reading disability due to deficits in phonological processing show impaired talker recognition even in their native language. Other studies suggest that the influence of phonological processing on talker identification is a gradient one, such that the detriment listeners experience when identifying talkers of non-native language reflects a continuum of experience and expertise with that language. Here we test the hypothesis that the gradient influences of reading ability on native and non-native talker identification will be observed for the range of reading abilities that mark unimpaired readers. Monolingual, English readers were assigned to either the average (n = 17) or advanced (n = 17) reading group based on a median split of aggregate performance across a standardized assessment battery for reading sub-skills and reading comprehension. All readers were trained to identify the voices of four English talkers and four French talkers during training phases. Following training, all readers were tested on retention of the trained sentences as well as generalization to novel sentences produced by the same talkers. The results indicated that compared to the average readers, the advanced readers (1) showed higher talker identification during training for both the native and non-native talkers, (2) required less exposure to learn the non-native voices, and (3) generalized the non-native voices to a greater degree. These results extend findings from

previous research to include a gradient effect of language competence on talker identification even among within-normal differences in reading ability.

Note

This thesis reflects a working version of a manuscript in collaboration with Dr. Rachel M. Theodore, Adriel John Orena (McGill University), and Linda Polka (McGill University). The manuscript related to this thesis project will be submitted and authorship will be shared with those named above.

Introduction

The literatures on speech perception and talker recognition are historically distinct, reflecting the long-standing view that separate aspects of the speech signal are used to cue meaning and talker identity. This view is challenged by recent findings indicating that these aspects of the signal are fundamentally intertwined in the course of spoken language processing. With respect to speech perception, numerous findings indicate that experience with a talker's voice facilitates speech perception (Theodore & Miller, 2010) and word recognition (Nygaard, Sommers, & Pisoni, 1994). With respect to talker recognition, listeners are better able to identify talkers of their native language compared to a non-native language (Perrachione & Wong, 2007), which has been taken as evidence that phonological ability, knowledge of the sound structure of language, is an important mediator of talker recognition. Given these findings, a complete model of spoken language processing must describe how listeners integrate these two sources of information in the course of language comprehension.

The relationship between language comprehension and talker identification has been examined by paradigms that use non-native speech. In a non-native language, the listener cannot access the linguistic information from the speech signal as they can in their native language. Accordingly, if language comprehension ability is decoupled from voice recognition ability, then there should be no difference in talker identification for native compared to non-native talkers. However, Perrachione, Del Tufo, and Gabrieli (2011) demonstrated a benefit for talker identification when listeners can comprehend the talker's message. Listeners were presented with talkers in both native and non-native languages. Talker identification was improved in the native language, where the listeners had the benefit of language comprehension, compared to performance in the non-native language. The results of this work indicate that linguistic

knowledge is recruited for talker identification when available. Other research has shown that comprehension *per se* is not necessary for the native-language benefit for talker recognition. Specifically, the native-language benefit is seen even in the absence of on-line language comprehension (Fleming, Giordano, Caldara, & Belin, 2014), pointing to a role for sub-lexical language influences.

Indeed, recent findings indicate that phonological knowledge is the putative factor in linking talker recognition and language processing. Specifically, adults with reading disability due to developmental dyslexia perform poorly on talker identification tasks in both native and non-native languages. Dyslexia is defined as a neurologically based, specific learning impairment that is characterized by unexpected difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities (Lyon, Shaywitz & Shaywitz, 2003; Pugh et al., 2000; Shaywitz & Shaywitz, 2005). It is widely recognized that people with dyslexia present with poor performance on phonological tasks (Ramus, 2003; Shankweiler et al., 1995). Perrachione et al. (2011) tested listeners with and without dyslexia on the ability to recognize voices in both their native and non-native language. They found that, like other studies (Perrachione & Wong, 2007; Fleming et al., 2014, Bregman & Creel, 2014), typical readers exhibited a strong language benefit with talker recognition improved in the native compared to the non-native language; however, the adults with dyslexia did not show such language-specific performance. Specifically, talker recognition in the native language was as poor as it was in the non-native language, suggesting that impaired phonological processing leads to decreased talker recognition, even when semantic comprehension is intact. Moreover, Perrachione et al. (2011) showed that the degree of impairment exerted a gradient influence on talker recognition.

Parea et al. (2014) extended these findings from the end-state adult system to a developing system in order to examine the possibility of using voice identification as an early identification marker for dyslexia in children. Adults and children with and without dyslexia participated in a talker identification task for native and non-native voices. Their results showed that the dyslexia groups performed significantly lower on talker identification compared to the typical readers. However, unlike in Perrachione et al. (2011), the dyslexia groups showed a native-language advantage for talker identification of the same magnitude as the typical groups. Relevant to the current work, these data suggest that the effects of phonological ability may not only influence talker identification in a native language, but may also influence non-native talker recognition.

Indeed, research has shown that some aspects of language processing exert a gradient influence on talker recognition. Specifically, Bregman & Creel (2014) examined the effects of age of acquisition on non-native voice recognition. In their study, English monolinguals and Korean-English bilinguals were tested on English and Korean voices. For the Korean-English bilinguals, some acquired both languages before the age of 5 years (i.e., early learners) and some acquired English after the age of 5 years (i.e., late learners). They found that age of acquisition was negatively correlated with rate of talker learning. Specifically, the early Korean-English bilinguals learned the English voices faster compared to the late Korean-English bilinguals. Strikingly, although language background influenced learning rate, it did not constrain the listeners' ability to generalize their experience. Once criterion for talker learning had been met, the ability to generalize this learning to novel utterances was equally robust for both groups (Bregman & Creel, 2014).

Viewed collectively, previous studies have demonstrated that talker identification is modulated by language ability. Specifically, healthy adults and children show a native-language benefit for talker identification, even when access to the lexical-semantic signal is removed, suggesting a strong role for phonological ability in mediating talker identification. Consistent with this hypothesis, adults with developmental dyslexia, a population with known deficits in phonological processing, show impaired talker recognition even in their native language, with degree of impairment exerting a gradient influence on talker recognition. Moreover, gradient effects of language proficiency on non-native voice recognition have also been observed. These findings suggest that in moving towards a model of spoken language processing that accounts for links between talker recognition and speech perception abilities, stability at the phonological level of processing may prove to be an important factor. However, future research is needed in order to determine whether phonological processing as captured in reading ability influences talker identification not just for individuals with reading disability, but also across the range of values that comprise unimpaired variation.

To this end, the current study examines talker identification in two groups of unimpaired readers, average readers, who perform near the middle of the normal distribution on reading assessments, and advanced readers, who perform near the top of the normal distribution on the same assessments. For both groups of readers, we examine their ability to (1) learn native and non-native voices, (2) retention of learning, and (3) generalization to novel utterances produced by the same voices. If the influences of reading ability previous observed for native speech reflect impairments specific to reading disability, then we predict that there will be no difference in learning or test between the two groups of unimpaired readers. If, however, phonological knowledge exerts a gradient influence on talker recognition as was shown for age of acquisition,

then we predict that the advanced readers will outperform the average readers on all measures of talker identification.

Methods

Participants

Thirty-six monolingual, native English speakers between the ages of 18 and 24 years (M = 20, SD = 2) were recruited for participation from the University of Connecticut community. All participants provided informed consent according to protocol approved by the University of Connecticut Institutional Review Board and were either paid or received partial course credit for their participation. Reponses to questionnaires developed in our laboratories confirmed that participants had no history of speech, language, hearing, or reading disorders and no knowledge of French. In order to confirm that differences in reading ability (described below) were not attributable to impairments in nonverbal intelligence, all participants completed the *Test of Nonverbal Intelligence - Fourth Edition* (TONI-4) and the Immediate Memory Index of the *Wechsler Memory Scales - Fourth Edition* (WMS-IV). Two participants were excluded because they scored below the 10^{th} percentile on one of these measures, leaving 34 participants who scored within normal limits for inclusion in the study. All participants passed a pure tone hearing screen on the day of testing, administered at 20 dB for octave frequencies between 500 Hz and 4000 Hz.

The 34 participants were assigned to the average or advanced reading group based on performance for a standardized assessment battery of reading sub-skills and reading comprehension (shown in Table 1). Specifically, a composite reading score was calculated for each participant (defined as mean percentile across the reading assessments) and a median split based on this measure determined the participant grouping. Mean percentile was 63 (SD = 10) for the average readers and 80 (SD = 5) for the advanced readers, which represent statistically

distinct distributions (t_{32} = -5.946, p < 0.001, d = -2.102). As shown in Table 1, this grouping adequately characterized performance between the groups for each of the components.

Stimuli

Auditory stimuli consisted of 12 English sentences and 12 French sentences that were matched in number of syllables and are described in detail by Vaiji (2004). Four native female speakers of each language produced each of the sentences for the respective language. Acoustic analyses confirmed that talkers of the two languages were equally discriminable on the basis of sentence duration, fundamental frequency, and variation in fundamental frequency. Two of the sentences were used during familiarization. Five of the sentences of each language were used during training and test phases, as described below. The remaining five sentences were only presented during the test phase in order to examine generalization of learning.

Visual stimuli consisted of eight cartoon faces, one for each talker. The faces were designed to be equally discriminable across the two languages.

Procedure

We used a modified version of the training paradigm outlined in Bregman & Creel (2014). Specifically, all participants completed a familiarization, training, and test phase in English and, separately, in French. Language order was counterbalanced across participants. All participants were tested individually in a sound-attenuated booth. Auditory stimuli were presented via headphones at a comfortable listening level held constant across participants. Visual stimuli were presented on a computer monitor and participants made their responses using a button box. Experiment presentation and data collection were controlled with the SuperLab software (version 4.5) on a Mac OS X system.

During familiarization, participants heard two sentences produced by each of the four talkers. Each sentence was paired with the appropriate cartoon face. Participants were directed to attend to each sentence and face in order to learn the talkers' voices.

The training phase consisted of blocks of 60 randomized sentences (5 sentences X 4 talkers X 2 repetitions). On each trial, listeners heard one sentence and were asked to indicate the name of the talker by choosing from one of two cartoon faces. Feedback was provided during training in the form of "CORRECT" or "INCORRECT," which was visually displayed after each trial along with the correct face. For each block, each face appeared equally often with every other face, and for each pair of faces, each face appeared equally often as the left or right face. Participants completed successive blocks of training until they met the learning criterion, defined as 85% correct or higher in a given block or the completion of eight training blocks. The test phase began following once the learning criterion was met. During test, listeners heard 120 randomized sentences [4 talkers X 10 sentences (5 trained and 5 novel) X 3 repetitions] and we asked to indicate the talker for each sentence. They made their choice from an array of the four cartoon faces presented during training. No feedback was provided at test, and the face array was constant for each trial.

Results

Training

For each participant, performance during training was calculated separately for each language in terms of (1) percent correct talker identification during the first block of training and (2) number of training blocks required to reach the learning criterion. Mean performance for each of the two reading groups is shown in Figure 1. Consider first performance during the first training block. Visual inspection of Figure 1, panel (a) suggests that both groups of readers showed increased talker identification for the English compared to the French talkers, which was expected based on previous findings showing a native language advantage for talker identification. However, for both the English and the French talkers, the advanced readers show heightened talker identification compared to the average readers. To confirm this pattern statistically, mean talker identification in the first training block was submitted to ANOVA with the within-subjects factor of language (English vs. French) and the between-subjects factor of reading ability (average vs. advanced). The results confirmed a main effect of language ($F_{1,32}$ = 83.077, $p < 0.001$, $\frac{2}{p} = 0.722$), with performance higher for the English ($M = 92.11$, $SD = 5.42$) compared to the French talkers ($M = 78.19$, $SD = 10.09$). There was also a main effect of reading group ($F_{1,32} = 5.493$, $p = 0.025$, $\frac{2}{p} = 0.146$), with performance in the advanced reading group ($M = 87.70$, $SD = 4.88$) higher compared to the average reading group ($M = 82.60$, $SD = 7.52$) There was no interaction between language and reading group ($F_{1,32} = 1.191$, $p = 0.283$, $\frac{2}{p} = 0.036$).

Now consider performance with respect to the number of training blocks required to meet the learning criterion, shown in panel (b) of Figure 1. Visual inspection shows a robust effect of language on number of training blocks, such that for both reading groups, criterion was met with fewer training blocks for the English compared to the French voices. However, this language

influence appears to be mediated by reading ability such that the difference between the English and French voices is attenuated for the advanced readers compared to the average readers. To investigate these patterns statistically, we submitted number of training blocks to ANOVA following the structure outlined above. The native language benefit for talker identification was confirmed, with the ANOVA showing a robust main effect of language ($F_{1,32} = 37.828$, $p < 0.001$, $\eta_p^2 = 0.542$) such that fewer training blocks were required to meet criterion for the English ($M = 1.09$, $SD = 0.288$) compared to the French voices ($M = 3.79$, $SD = 2.85$). There was also a main effect of reading ability ($F_{1,32} = 7.902$, $p = 0.008$, $\eta_p^2 = 0.198$), with fewer training blocks required for the advanced ($M = 1.79$, $SD = 0.99$) compared to the average readers ($M = 3.09$, $SD = 1.62$). Moreover, the ANOVA showed a reliable interaction between language and reading ability ($F_{1,32} = 6.454$, $p = 0.016$, $\eta_p^2 = 0.168$). Independent t-tests showed that for the French voices, the advanced readers required fewer training blocks to meet the learning criterion compared to the average readers ($t_{32} = 2.693$, $p = 0.011$, $d = 0.952$). For the English voices, this trend was numerically present, but did not reach threshold for statistical significance ($t_{32} = 1.852$, $p = 0.073$, $d = 0.655$).

Collectively, the results from the training data indicate that reading ability influenced the degree to which listeners could learn to identify the talkers' voices. With respect to accuracy in the first block, the advanced readers showed increased talker identification accuracy compared to the average readers for both the native and non-native voices. With respect to amount of exposure required to meet the learning criterion, differences between the two reading groups emerged only for the non-native voices.

Test

Performance at test was measured in terms of percent correct talker identification, which was calculated for each participant separately for the English and French voices and for the trained and novel sentences. Figure 2 shows mean accuracy for the average and advanced reading groups for the English and French voices, shown in panels (a) and (b), respectively. Visual inspection of this figure suggests that the average and advanced readers performed similarly at test for the English voices, but that the advanced readers outperformed the average readers for the French voices, specifically with respect to the novel French sentences.

Percent correct talker identification was submitted to ANOVA with the between-subjects factor of reading ability and the within-subjects factors of language (English vs. French) and sentence type (trained vs. novel). Consider first the main effects. There was a significant main effect of language ($F_{1,32} = 448.255$, $p < 0.001$, $\eta_p^2 = 0..933$), as expected, with performance overall higher for the English ($M = 91.84$, $SD = 8.79$) compared to the French voices ($M = 50.86$, $SD = 13.61$). There was also a significant main effect of reading ability ($F_{1,32} = 5.861$, $p = 0.021$, $\eta_p^2 = 0.155$), with performance for the advanced readers ($M = 75.15$, $SD = 9.17$) higher compared to the average readers ($M = 67.55$, $SD = 9.13$). There was no main effect of trial type ($F_{1,32} = 0.522$, $p = 0.475$, $\eta_p^2 = 0.016$). With respect to the interactions, there was no interaction between trial type and reading group ($F_{1,32} = 1.601$, $p = 0.215$, $\eta_p^2 = 0.048$), but there was an interaction between language and reading group ($F_{1,32} = 4.525$, $p = 0.041$, $\eta_p^2 = 0.124$) and between language and trial type ($F_{1,32} = 12.110$, $p < 0.001$, $\eta_p^2 = 0.275$). Critically, the three-way interaction between language, reading group, and trial type was reliable ($F_{1,32} = 7.576$, $p = 0.010$, $\eta_p^2 = 0.191$). Results of independent t-tests revealed that there was no difference between average and advanced readers for the trained English sentences ($t_{32} = -1.269$, $p = 0.214$, $d = -0.448$), the novel English

sentences (t_{32} = -0.931, p = 0.359, d = -0.329), or the trained French sentences (t_{32} = -1.627, p = 0.113, d = -0.575), but that there was a striking difference between the two reading groups for the novel French sentences (t_{32} = -3.474, $p < 0.001$, d = -1.228), with performance higher for the advanced readers (M = 56.67, SD = 12.18) compared to the average readers (M = 40.98, SD = 14.08).

These results suggest that the reading related differences in talker identification observed during training influenced performance at test. Specifically, we observed a main effect of reading ability, with performance overall better for the advanced compared to the average readers. However, the robust interaction between reading ability, language, and trial type suggests that the locus of that main effect concerns the fact that the average readers did not generalize to novel French sentences to the same degree as the advanced readers.

Discussion

There is a growing body of evidence indicating not only that listeners integrate talker identity and linguistic content, but that these aspects can mutually inform and constrain each other. Previous research suggests that language ability, as measured in terms of stability in phonological processing, exerts a gradient influence on talker identification (e.g., Bregman & Creel, 2014; Perrachione et al., 2011). The results here are consistent with this account. Adults with reading ability near the top of the normal distribution showed heightened talker identification compared to adults with reading ability near the middle of the distribution. This finding extends earlier work showing impaired talker recognition in adults with dyslexia to include a gradient influence of phonological processing on talker identification even within the unimpaired range of reading ability.

Accuracy of talker identification at the first training block is reflective of talker identification with very limited exposure to the talkers' voices and it was here that we observed a talker identification benefit for both the native and non-native voices. These results can be compared to Perrachione et al. (2011), who also measured talker identification given limited exposure. Our results extend their findings to include gradient effects of reading ability on talker recognition. That is, they showed a striking difference between typical and dyslexic participants on native voice recognition, here we provide evidence that this effect holds when considering varying degrees of phonological ability within the unimpaired population. Moreover, the reading advantage was equivalent for both the native and non-native languages.

In the current study, participants trained on talkers' voices until they had met a criterion of 85% accuracy on voices before training ended. This aimed to ensure that all participants, regardless of reading ability, learned the talkers' voices to the same degree. It also served as a

measure for talker learning rate (number of training blocks required to reach criterion). The average reading group required a statistically significant amount of additional training on talkers to achieve criterion as compared to the advanced reading group, suggesting that reading ability is reflective of perceptual learning rate, findings that are consistent with Bregman & Creel (2014). However, unlike previous work, the present data suggests that while differences in learning rate exist between the average and advanced reading groups, they are much stronger in the non-native compared to the native language. Recall that there were two ways in which readers could meet the learning criterion during training, either by scoring 85% correct or higher in a given training block, or by completing eight training blocks. Of the 34 participants tested in the current work, nine reached the maximum number of training blocks without meeting the established 85% correct criterion. Strikingly, eight of these nine individuals were in the average reading group, which suggests that to some degree, the current work underestimates the amount of exposure that these readers would have required to learn the French voices to our learning criterion. It also opens the door for future inquiry that allows for more fine-grained learning measures and for increased opportunities to reach learning criterion.

With respect to performance at test, the current findings suggest that the effects of reading ability were limited to performance in the non-native language, specifically with respect to identification for novel items. These findings support the Bregman & Creel (2014) study, which found that although the effects of age of acquisition on talker recognition were robustly observed with respect to talker learning rate, once the voices were learned, generalization to novel utterances was equivalent for early and late learners of English. In our study, reading ability did not pattern like age of acquisition. Specifically, advanced readers compared to average readers require less time to learn the non-native voices and generalized to a greater

degree. This finding suggests that factors that influence linguistic competence, such as reading ability and age of acquisition, may not show identification influences on voice recognition.

The current work provides critical data in moving towards a principled account of the integration between talker identification and language ability. First, the effects of reading ability on talker identification accuracy were observed as a gradient along a continuum of reading ability. Second, there was a difference in talker identification accuracy between average and advanced reading groups in both native and non-native languages. It is striking differences in native phonological ability influenced non-native talker recognition, given that the phonological structures of the two languages are distinct. This raises the possibility that the locus of this effect is not limited to phonology (Perea et al., 2014). Other potential contributing factors to the difference observed may be general auditory deficits (Studdert-Kennedy & Mody, 1995), or a reduced ability to access and analyze pitch information (Xie & Meyers, 2015). That is, here we attribute the observed differences in the reading groups to an underlying difference in phonological ability that present as differences in performance on the standardized assessments of reading sub-skills and reading comprehension. An alternative possibility is that there is an underlying cognitive, auditory, or neural difference that gives rise to differential performance on both the reading and talker identification measures. For example, perhaps cognitive differences with respect to memory interact with phonological stability. Though this was not manipulated directly in the current study, we did collect measures on auditory memory in terms of the Immediate Memory Index (IMI) of the WMS - IV. We required that all participants scored within normal limits on this measure, but as shown in Table 1, the average readers performed slightly below the advanced readers. It may thus be the case that auditory memory influences talker recognition either on its own, or in conjunction with phonological ability. However, this

metric is not optimal for answering this question, given that half of the components of the IMI are language-dependent tasks. Accordingly, it is possible that the differences observed in IMI score simply reflect the same difference we observe in phonological ability, as they both draw on language ability. Nonetheless, it is an interesting avenue for future research. Future work is aimed at examining these possibilities.

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Table 1

Mean, standard deviation (in parentheses), *t*, *p*, and Cohen's *d* for the average and advanced readers for each component of the standardized assessment battery and the composite reading score. The *t* and *p* values reflect those derived from independent t-tests (*df* = 32) for each assessment measure. See the main text for a description of each assessment.

Assessment	**Average Readers**	**Advanced Readers**	***t***	***p***	***d***
TONI – 4	40 (21)	47 (22)	-0.946	0.351	-0.325
WMS – 4: IMI	60 (22)	75 (18)	-2.170	0.038	-0.746
CTOPP: Elision	51 (22)	66 (10)	-2.780	0.009	-0.878
CTOPP: Blending	60 (29)	75 (14)	-1.927	0.063	-0.703
CTOPP: Nonword Repetition	65 (23)	72 (17)	-0.971	0.339	-0.346
RAN: Rapid Digit Naming	74 (7)	83 (6)	-3.942	< 0.001	-1.381
RAN: Rapid Letter Naming	67 (9)	81 (8)	-4.714	< 0.001	-1.644
RAS: 2 – Set	71 (10)	86 (7)	-4.694	< 0.001	-1.622
TOWRE: Sight Words	61 (22)	86 (13)	-4.004	< 0.001	-1.384
TOWRE: Decoding	62 (15)	84 (12)	-4.767	< 0.001	-1.620
WRMT – III: Word ID	65 (24)	86 (14)	-3.121	0.004	-1.069
WRMT – III: Word Attack	56 (23)	75 (21)	-2.596	0.014	-0.863
WRMT – III: Comprehension	65 (22)	84 (12)	-3.170	0.003	-1.072
Composite Reading Score	64 (10)	80 (5)	-5.946	< 0.001	-2.150

Figure 1

Mean percent correct talker identification during the first training block (panel a) and mean number of training blocks required to meet learning criterion (panel b) for the English and French voices for the average and advanced reading groups. Error bars indicate standard error of the mean.

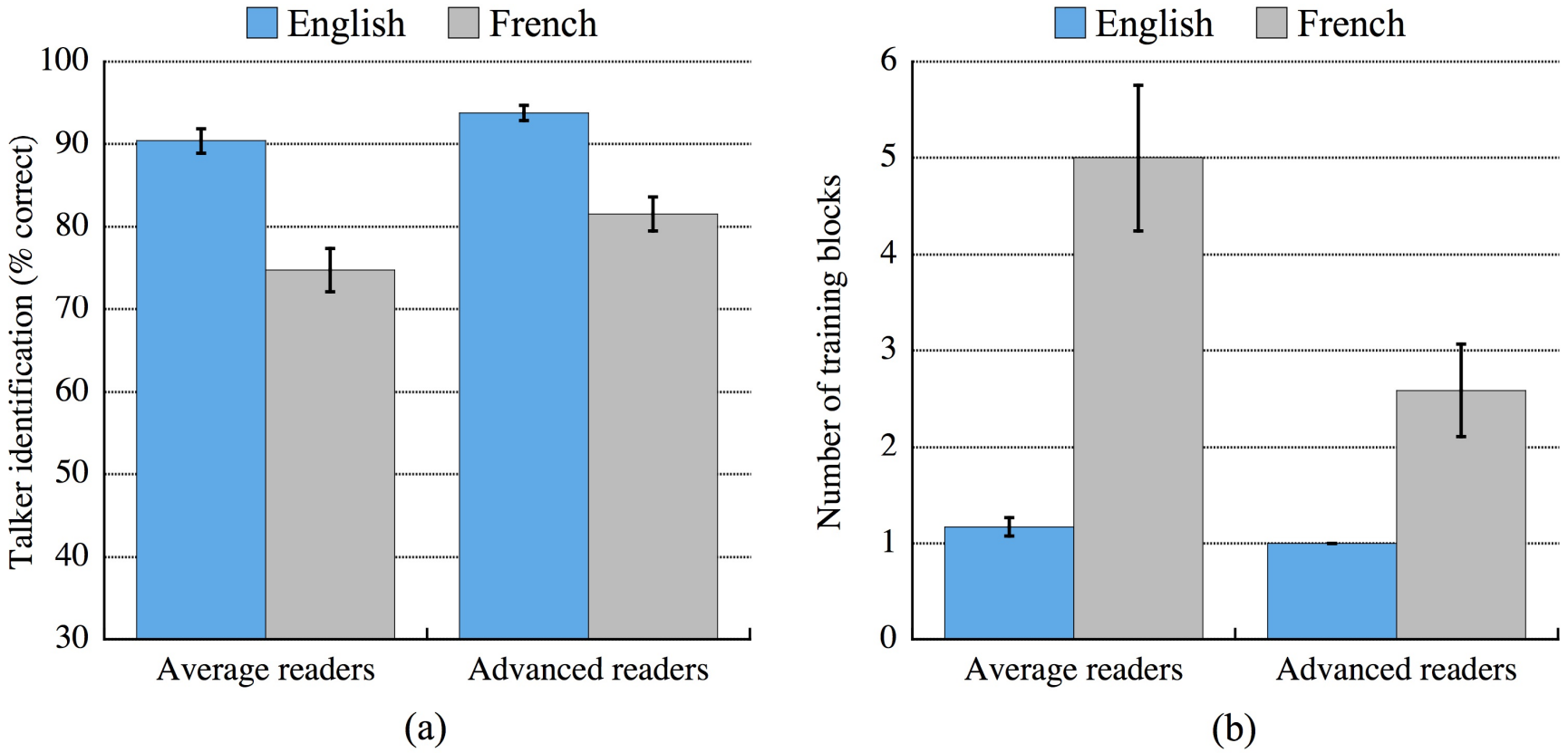

Figure 2

Mean percent correct talker identification at test for the trained and novel sentences for the average and advanced reading groups for the English (panel a) and French (panel b) voices. Error bars indicate standard error of the mean.