THE RELATIONSHIP BETWEEN SPEECH RECOGNITION IN NOISE AND READING ABILITIES

by

Hannah Rae Moore

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Hannah Rae Moore

Greenville, NC

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Approved by:

Andrew J. Vermiglio, AuD, Thesis Advisor

Department of Communication Sciences and Disorders

College of Allied Health Sciences

Abstract

The primary goal of the current study was to determine the relationship between speech recognition in noise ability and reading ability. A secondary goal of the study was to determine whether the binaural advantage (listening to speech-in-noise with two ears versus one) and the binocular advantage (reading with two eyes versus one) were related. Thirty-nine native English-speaking young adults with normal pure-tone thresholds from 250-4000 Hz participated in the study. The Hearing in Noise Test (HINT) was used to evaluate speech recognition in noise ability. The Test of Silent Contextual Reading Fluency (TOSCRF-2) was used to evaluate reading ability. No significant relationships were found between speech-in-noise thresholds and reading scores. Additionally, no significant relationships were found between the binaural advantage and the binocular advantage.

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Introduction

Past research has indicated that a possible connection may exist between speech recognition in noise ability and reading ability. Brady, Shankweiler, & Mann (1983) and Ziegler et al. (2009) reported a significant positive relationship between speech recognition in noise ability and reading; however, both of these studies used poor readers instead of readers with average or better reading ability. In contrast, Miller et al. (2018) found a non-significant correlation between speech recognition in noise ability and reading ability for average or better readers. Therefore, the relationship – or lack thereof – between speech recognition in noise ability and reading ability is still unclear.

According to AAA (2010), reading and speech recognition in noise deficits are common symptoms found for individuals seen for central auditory processing disorder (CAPD) evaluations. This implies that these two symptoms of CAPD are somehow related to each other. However, the relationship between speech recognition in noise ability and reading ability remains unclear (Miller et al., 2018). One hypothesis is that deficiencies in phonological representations connects reading and speech recognition in noise ability (Brady et al., 1983). Another hypothesis is that lack of access to phonological representations during development may cause deficits in reading and listening to speech-in-noise (Ramus & Szenkovits, 2008).

The Binaural Advantage

The binaural advantage, or the advantage of listening to speech-in-noise with two ears vs. one, has been investigated in multiple studies. Vermiglio et al. (2017) investigated the binaural advantage using the Hearing in Noise Test (HINT; Nilsson et al., 1994; Vermiglio, 2008). Speech recognition in noise ability was determined in both binaural and monaural conditions for Noise Front, Noise Left, and Noise Right. The binaural advantage was calculated by subtracting the binaural from the monaural thresholds for each condition. The average binaural advantages for the HINT conditions, with the spatial separation of the target speech and noise, was 11.25 dB ($p < 0.01$).

The Binocular Advantage

The binocular advantage has been investigated in multiple studies (Jainta, Blythe, and Liversedge, 2014; Johansson, et al., 2014). Jainta et al. (2014) investigated the binocular advantages in reading and lexical processing. Lexical processing in reading is the process of recognizing and comprehending the meaning of a word and can be measured by recording the amount of time it takes for a reader to process a word. Jainta et al. (2014) measured this by measuring the fixation duration, which includes the duration of fixation on a target word and the sum of all fixations on the target word. To do this, they presented target words in two conditions: binocular-monocular and monocular-monocular. In the binocular-monocular condition, the target word was presented first to both eyes, then to one eye. In the monocular condition, the target word was presented twice to only one eye. When the target word was presented monocularly after a binocular preview, a lexical processing advantage was observed in comparison to a solely monocular presentation ($p < 0.01$). This indicates that lexical processing became more efficient when the subject viewed the target word binocularly. Overall, these results show that binocular reading is much more efficient than monocular reading and is critical to effective word identification and lexical processing (Jainta et al., 2014).

Johansson, et al. (2014) investigated monocular vs binocular reading performance by having participants read texts in three ocular conditions, monocular left, monocular right, and binocular, at different levels of contrast or visual sharpness, totaling 9 conditions. The words per minute for reading score was determined, as well as comprehension scores that were determined by asking the subjects about the content of the texts. For the analysis, the right and left monocular values were averaged to create one monocular vision score. A two-way ANOVA analysis indicated that there was a significant main effect of viewing condition, monocular or binocular ($p < 0.01$). Additionally, the mean monocular reading speed, or words read per minute, was slower than binocular. Finally, the mean fixation duration of binocular reading was decreased compared to monocular reading ($p < 0.01$), indicating that the participants spent less time looking at each word in the binocular condition. These results indicated that binocular reading is faster and more efficient than monocular reading.

Speech Recognition in Noise Ability vs. Reading Ability

Anderson et al. (2010) investigated the relationship between speech recognition in noise ability and reading ability for 66 children, ages 8-14. Speech recognition in noise ability was evaluated using the HINT. Reading ability was evaluated using the Test of Word Reading Efficiency (TOWRE-T; Torgesen et al., 1999). The TOWRE-T is an assessment of sight word recognition. The participant's task was to both read and say nonwords and discriminate real words from nonwords. Anderson et al. (2010) found a weak but statistically significant relationship between HINT Noise Front thresholds and the TOWRE-T scores ($r = 0.227$; $p = 0.024$), indicating that children with poorer speech recognition in noise ability have poorer reading ability.

Foo, et al. (2007) evaluated the relationship between reading span and speech-in-noise ability for participants with mild to moderate hearing loss. Speech recognition in noise ability was evaluated using Hagerman sentences (Hagerman and Kinnefors, 1995) and the HINT, in various modulated and unmodulated noise conditions for both tests. Reading span, or the ability to recall previously seen words correctly, was evaluated using the test developed by Ronnberg

(1989). Foo et al. (2007) reported that reading span predicted speech recognition in noise ability, regardless of what type of noise was used to conduct the speech recognition test (r = -0.47 to -0.67).

Miller, et al. (2018) investigated the relationship between speech recognition in noise and reading abilities in school age children. Bench-Kowal-Bamford (BKB; Bench, Kowal, Bamford, 1979) sentences were used to identify speech-in-noise ability in four masker conditions: speech-shaped steady-state noise, temporally modulated noise, spectrally modulated noise, and a two-talker masker. Reading was evaluated using two subtests of the Test of Word Reading Efficiency (TOWRE-2; Torgeson, et al., 1999) and two subtests of the Woodcock Reading Mastery Tests - Third Edition (WRMT-III; Woodcock, 2011). The two subtests of the TOWRE-2 included in this study were the Sight Word Efficiency subtest, which evaluates the subject's ability to recognize words as whole units, and the Phonemic Decoding Efficiency subtest, which tests the subject's ability to sound out nonwords. The two subtests of the Woodcock Reading Mastery Tests included in this study were the Word Identification subtest, which requires the participant to read words that gradually increase in complexity, and the Word Attack subtest, which measures sound-symbol correspondence. Miller et al. (2018) reported no significant relationships between speech perception and reading ability.

Purpose

The primary goal of the current study was to determine the relationship between speech recognition in noise ability and reading ability. A secondary goal of the study was to determine whether the binaural advantage (listening to speech-in-noise with two ears versus one) and the binocular advantage (reading with two eyes versus one) were related. Speech recognition was evaluated in speech-shaped, steady-state noise in conditions with and without the spatial separation of the target speech and the masker. All speech-in-noise conditions were measured binaurally. Additionally, the Noise Side conditions were measured monaurally (unshadowed ear) in order to determine the binaural advantage. Reading was tested in three conditions: binocular, monocular right, and monocular left.

It was hypothesized that a negative relationship would be found between speech recognition in noise ability and reading ability, where a better reading score would be associated with a better (more negative) HINT threshold. It was also hypothesized that a statistically significant positive correlation would be found between the binaural advantage for speech recognition in noise ability and the binocular advantage for reading. It was also hypothesized that statistically significant different results would be found across listening and reading conditions.

The following research questions were investigated:

1. What is the relationship between speech recognition in noise and reading abilities?
2. What is the relationship between the binaural advantage for speech recognition in noise ability vs. the binocular advantage for reading ability?
3. What are the differences between monaural, binaural, monocular, and binocular test conditions for both the HINT and the TOSCRF-2?

Methods

Permission to conduct this research study was obtained from the East Carolina University Institutional Review Board. Forty-one female participants were tested in this study. The participants were college-aged students who were offered extra credit in a course for participating in the study. The average age of the students was 20.4 years (standard deviation: 0.79). Participants were required to have normal pure tone thresholds (≤ 25 dB HL for 250-4000 Hz) with clear outer ear canals and be a native speaker of English in order to participate in this study. Two participants were omitted due to unreliable data, lowering the total number of participants to 39.

Hearing in Noise Test

The Hearing in Noise Test (HINT; Nilsson et al., 1994; Vermiglio, 2008) is a measure the ability to recognize speech in speech-shaped, steady-state noise. Short, simple American English sentences are presented in 65 dBA noise. The HINT uses Knowles Electronics Mannequin for Auditory Research (KEMAR) head-related transfer functions (HRTFs) under headphones to simulate a sound field environment. Telephonics TDH-50P headphones were used to deliver the stimuli. The sentences presented to the participant are selected from a database of 12 20-sentence lists, each phonemically balanced and equally difficult (Vermiglio, 2008). Each HINT condition was tested with one list of 20 sentences. All HINT conditions were randomized. Using an adaptive protocol, the level of the sentence presentation varied based on the response of the participant. The HINT threshold is the signal-to-noise ratio (SNR) where the participant correctly recognizes 50% of the target sentences.

Sentences were presented at 0° in noise presented from 0°, 90°, and 270° for the Noise Front, Noise Right, and Noise Left conditions, respectively (Figure 1). For the monaural conditions, sentences were presented at 0° while noise was presented from 270° and from 90° for the monaural Noise Left and monaural Noise Right conditions, respectively (Figure 2). The unshadowed ear was used for the monaural listening conditions. The average binaural advantage was calculated by averaging the left and right binaural advantages. The HINT stimuli were presented using custom software from the House Ear Institute in Los Angeles, CA.

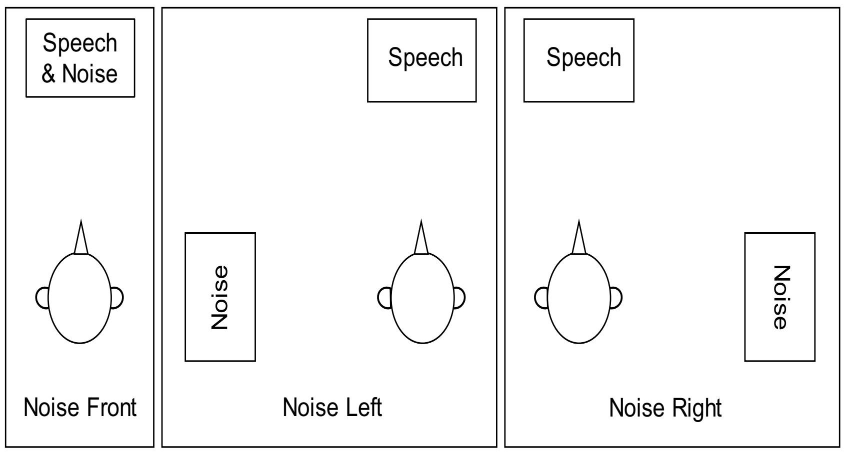

Figure 1. HINT binaural conditions.

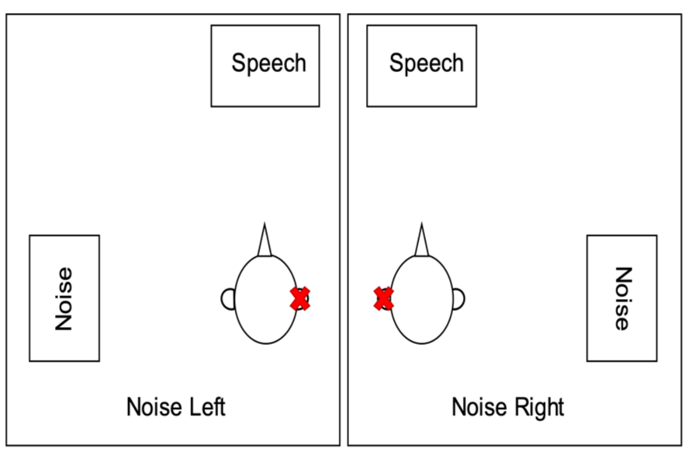

Figure 2. HINT monaural conditions.

Test of Silent Contextual Reading Fluency

The Test of Silent Contextual Reading Fluency-Second Edition (TOSCRF-2; Hammill et al., 2006) was used to measure reading ability. The TOSCRF-2 is a measure of word identification in a sentence context. The TOSCRF-2 was administered in three visual field conditions: binocular, monocular right, and monocular left. To isolate the visual fields, an eye patch and tissue were used to completely cover the non-test eye (Figure 3). In the monocular right condition, the participant used only their right eye to complete the reading protocol. In the monocular left condition, the participant used only their left eye. The three reading conditions were randomized. The index score is the total number of correct words the subject is able to identify or delineate within 3 minutes. The binocular advantage is calculated by subtracting the monocular reading performance from the binocular reading performance.

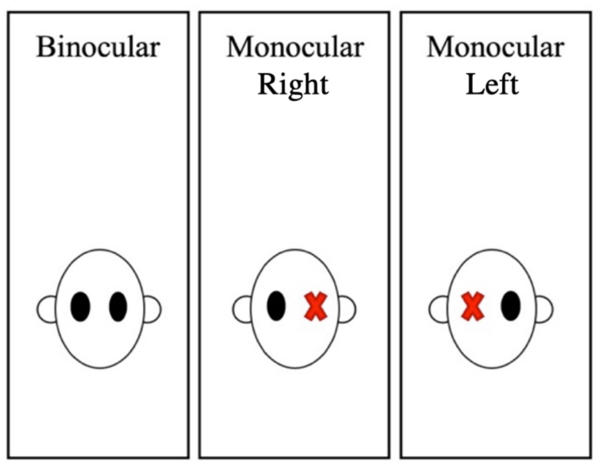

Figure 3. TOSCRF-2 reading conditions.

Results

Descriptive statistics are presented in Table 1 for the HINT thresholds, and includes the means, standard deviations, minimums, maximums, and ranges for each HINT condition. A more negative threshold represents better performance. Overall, participants performed best for the binaural Noise Side conditions. The mean HINT thresholds are presented in Figure 4. A repeated measures ANOVA was conducted to investigate the main effect of HINT Condition (Noise Front, Noise Right, Noise Left, Monaural Noise Right and Monaural Noise Left) on HINT thresholds. This analysis revealed that the main effect of HINT Condition was statistically significant (F value is 834.3299 for masker location, $p < 0.0001$). A post hoc analysis was conducted using matched-pairs t-tests. Significant differences were found between all combinations of matched-pairs ($p < 0.0001$) with the exception of Noise Left and Noise Right thresholds and between monaural Noise Left and monaural Noise Right thresholds.

	HINT Binaural Noise Front	HINT Binaural Noise Right	HINT Binaural Noise Left	HINT Composite Score	HINT Monaural Noise Left	HINT Monaural Noise Right	HINT Binaural Advantage Noise Right	HINT Binaural Advantage Noise Left
Mean	-2.38	-8.97	-8.86	-5.65	2.49	2.23	11.24	11.31
SD	0.94	1.26	1.29	0.74	1.04	1.24	1.57	1.53
n	39	39	39	39	39	39	39	39
Min	-4.7	-11.7	-11.9	-7.5	0.5	-0.2	7.8	8.2
Max	-0.2	-5.3	-5.6	-3.8	4.5	5.4	14.2	15.4
Range	4.5	6.4	6.3	3.7	4	5.6	6.4	7.2

Table 1. Descriptive statistics for speech recognition in noise results in dB SNR for HINT steady-state conditions, binaural and monaural. The binaural advantages are reported in dB

Descriptive statistics are presented in Table 2 for the TOSCRF-2 raw scores, including the means, standard deviations, minimums, maximums, and ranges for all reading conditions. Overall, participants performed best in the binocular condition vs. the monocular conditions, indicating a binocular advantage for reading ability. The mean TOSCRF-2 index scores are presented in Figure 5 for the TOSCRF-2. A repeated measures ANOVA was conducted to investigate the main effect of reading condition (binocular, monocular right, monocular left) on reading performance. This analysis revealed that the main effect of reading condition was statistically significant (F value is 4.777 for masker location, $p = 0.0143$). A post hoc analysis was conducted using matched-pairs t-tests. Significant differences were found between monocular right and binocular scores (mean difference = -3.39, $p = 0.042$) and between monocular left and binocular scores (mean difference = -4.39, $p = 0.003$). No significant difference was found between monocular right and monocular left scores.

	TOSCRF-2 Binocular	TOSCRF-2 Monocular Right	TOSCRF-2 Monocular Left	TOSCRF-2 Binocular Advantage Right	TOSCRF-2 Binocular Advantage Left	TOSCRF-2 Average Binocular Advantage
Mean	101.5	98.1	97.1	3.38	4.38	3.88
SD	13.29	9.88	12.09	10.03	8.76	8.72
n	39	39	39	39	39	39
Min	64	71	65	-21	-13	-17
Max	129	123	126	23	21	22
Range	65	52	61	44	34	39

Table 2. Descriptive statistics for the TOSCRF-2 index scores (TOSCRF-2 monocular conditions, binocular conditions, and the binocular advantages).

The correlation matrices for HINT thresholds vs. reading conditions are presented in Table 3 and Table 4. No significant relationships were found between speech recognition in noise ability vs. reading ability. Figure 6 shows the relationship between the HINT Composite Scores vs. TOSCRF-2 binocular index scores. The solid line represents the 5th percentile for the TOSCRF-2 binocular index score. Index scores more negative than the solid line represent reading performances below normal limits. The dashed line in Figure 6 represents the 5th percentile for the HINT Noise Composite score. HINT scores more positive than the dashed line represent speech recognition in noise performances below normal limits. The relationship between binaural and binocular advantages for speech recognition in noise and reading ability, respectively are presented in Figure 7. The solid line represents the 5th percentile for the TOSCRF-2 average binocular advantage, and the dashed line represents the 5th percentile for the HINT average binaural advantage. Advantages less than the solid and dashed lines are below normal limits. No statistically significant relationship was found between the binaural advantage for speech recognition in noise ability and the binocular advantage for reading ability. A monocular reading advantage was found for 31% of the participants and a binocular reading advantage was found for 69% of the participants (Figure 7).

	TOSCRF-2 Binocular Index score
HINT Noise Front	-0.2728 (0.0929)
HINT Noise Right	0.0383 (0.8171)
HINT Noise Left	0.0242 (0.8835)

Table 3. Correlation matrix for the HINT binaural thresholds vs. the TOSCRF-2 binaural index Score. The *p*-values are in parentheses.

	TOSCRF-2 Monocular Right Index score	TOSCRF-2 Monocular Left Index score
HINT Monaural Right	-0.0212 (0.8978)	0.0085 (0.9589)
HINT Monaural Left	-0.1353 (0.4115)	0.0710 (0.6677)

Table 4. Correlation matrix for the HINT monaural thresholds vs. the TOSCRF-2 monaural index Scores. The *p*-values are in parentheses.

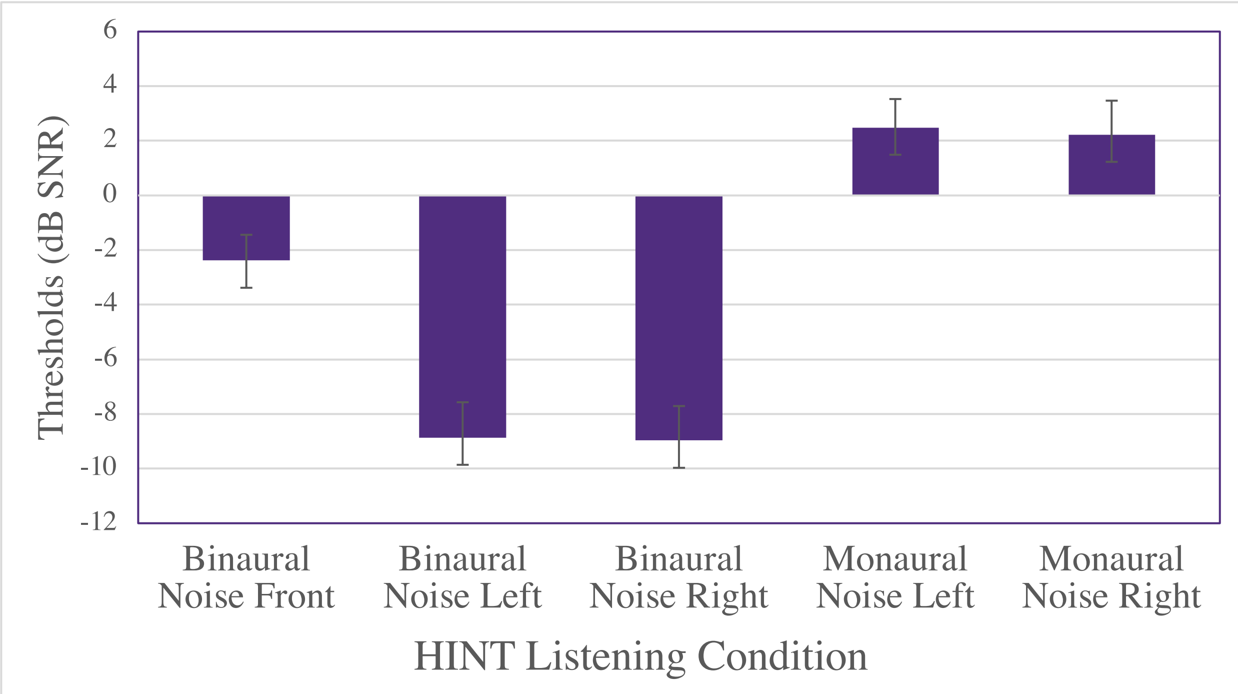

Figure 4. Mean HINT thresholds for all conditions. Error bars indicate one standard deviation.

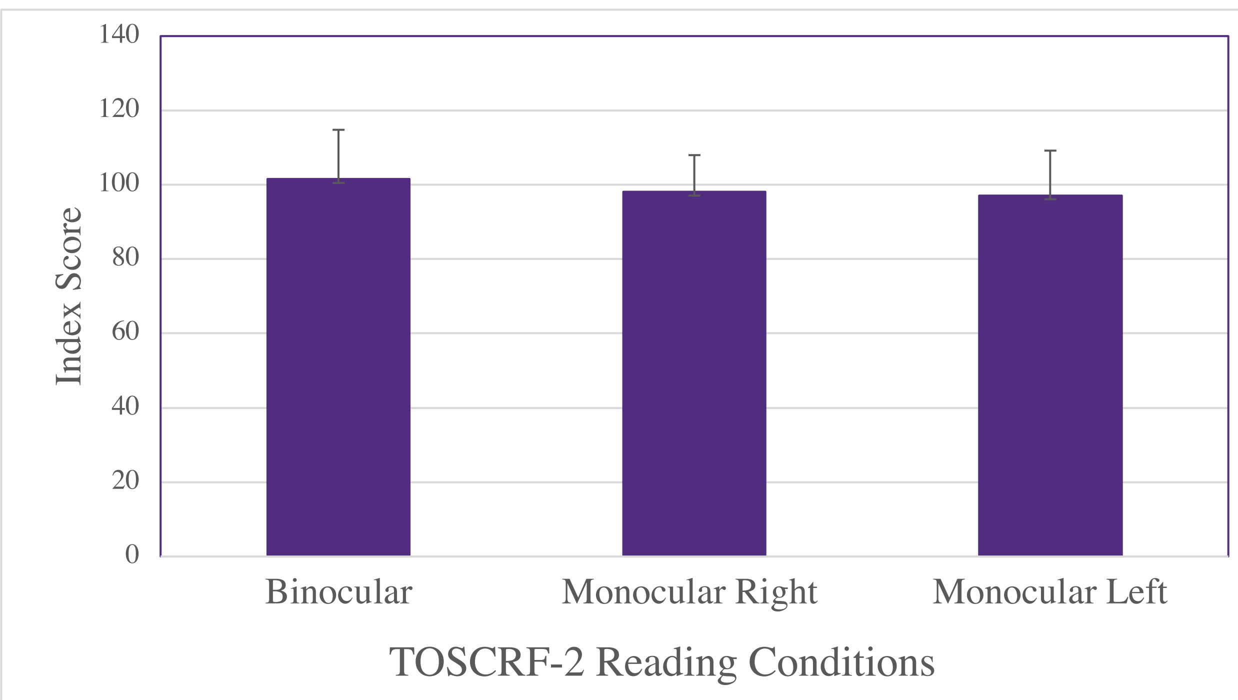

Figure 5. Mean index scores for all TOSCRF-2 reading conditions. Error bars indicate one standard deviation.

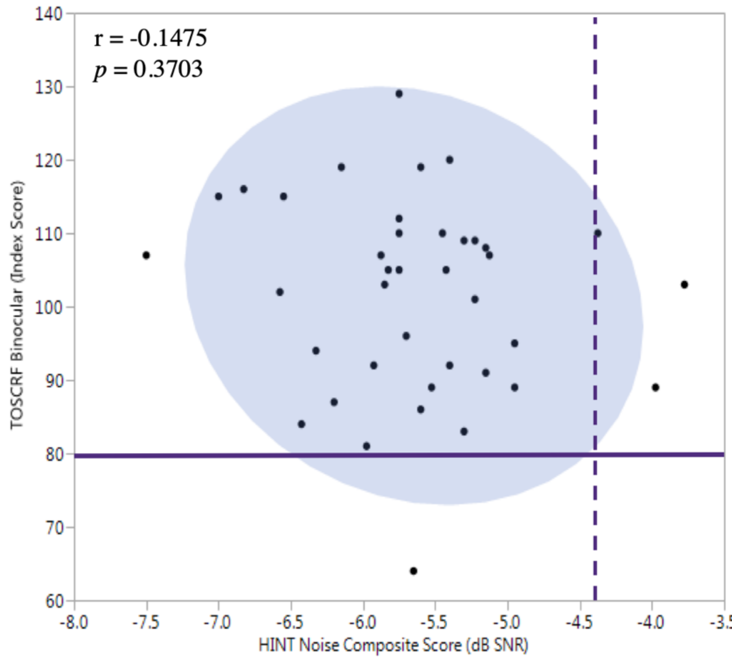

Figure 6. HINT Composite score vs. TOSCRF-2 binocular index score. The solid line represents the 5th percentile for the TOSCRF-2 binocular index score, and the dashed line represents the 5th percentile for the HINT Composite score.

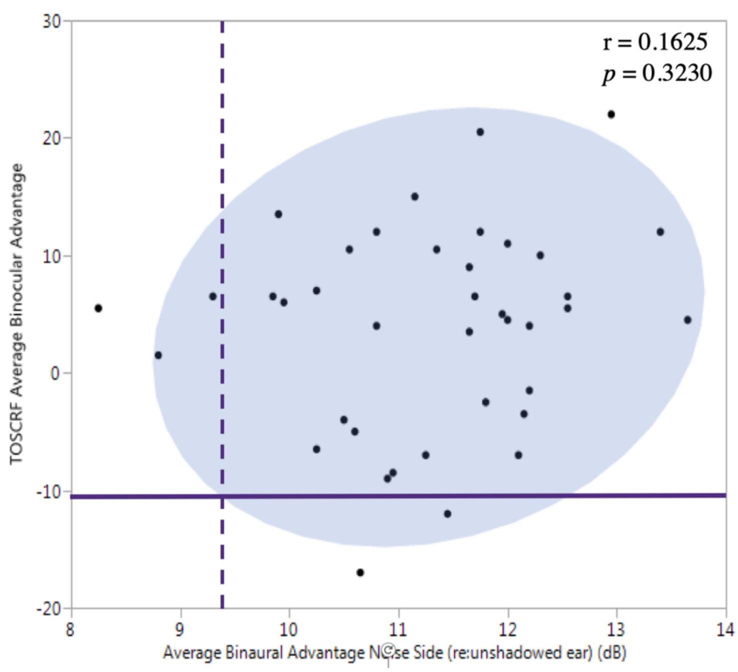

Figure 7. HINT average binaural advantage Noise Side vs. TOSCRF-2 binocular advantage. The solid line represents the 5th percentile for the TOSCRF-2 average binocular advantage, and the dashed line represents the 5th percentile for the HINT average binaural advantage.

Discussion

The primary goal of the present study was to determine the relationship between reading and speech recognition in noise abilities. No significant relationships were found between speech recognition in noise thresholds vs. reading scores. The secondary goal was to determine the relationship between the binaural advantage for speech recognition in noise and the binocular advantage for reading. No significant relationship was found between binaural speech recognition in noise thresholds vs. binocular reading scores.

The HINT thresholds were consistent with Vermiglio, et al. (2017). Vermiglio et al. (2017) reported a HINT Noise Front Score of -1.76 dB SNR, which is consistent with the current study's HINT Noise Front score of -2.38 dB SNR, a HINT Noise Right score of -8.38, which is consistent with the current study's HINT Noise Right score of -8.97 dB SNR, and a HINT Noise Left score of -8.58 dB SNR, which is consistent with the current study's HINT Noise Left score of -8.86 dB SNR. Additionally, Vermiglio et al. (2017) reported a binaural advantage Noise Right of 10.92, which is consistent with the current studies binaural advantage Noise Right of 11.24, and a binaural advantage Noise Left of 11.58, which is consistent with the current study's binaural advantage Noise Left of 11.31. Thirty-one percent of participants in the present study performed better on the reading test for the monocular rather than the binocular reading conditions. This is in contrast to the findings of Jainta, Blythe, and Liversedge, 2014; Johansson, et al., 2014. These authors reported a binocular advantage for the majority of their participants.

Miller et al. (2018) investigated the relationship between speech perception using a two-talker masker vs. reading ability for a group of forty-four typically developing third and fourth graders. They reported no significant relationships between speech recognition in noise and reading abilities. Consistent with Miller et al. (2018), no significant relationships were found between speech recognition in steady-state noise and reading ability in the present study. Furthermore, no significant relationship was found between the binaural advantage for speech recognition in noise ability and the binocular advantage for reading ability.

Ziegler et al. (2009) also investigated the relationship between speech recognition in noise ability and reading ability. They tested nineteen children with normal pure-tone thresholds between ages 8:6 and 12:1. Ziegler et al. found a significant relationship between speech recognition in noise ability and reading ability. However, contrary to our study, the participants had dyslexia. Perhaps Ziegler et al. found significant correlations between the variables because of a relatively large range of reading ability for the dyslexic participants.

Clinical Implications

AAA (2010) states that reading and speech recognition in noise deficits are common symptoms found for individuals seen for central auditory processing disorder (CAPD) evaluations, with the implication that these two abilities are related. This is not supported by the results of the current study and previous work (Miller et al., 2018). However, this is supported by Brady, Shankweiler, & Mann (1983) and Ziegler et al. (2009). Reading and speech recognition in noise abilities should be measured directly and not inferred from a diagnosis of CAPD.

Conclusion and Future Direction

The results of the present study indicate that for a group of young adults, the HINT and the TOSCRF-2 measure unrelated abilities. Additionally, no significant relationships were found between the binaural advantage for speech recognition in noise ability and the binocular advantage for reading. A monocular reading advantage was found for 31% of the participants as opposed to a binocular advantage for reading ability. Future research should investigate the effects of eye and ear dominance on the relationship between speech recognition in noise ability and reading ability.

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