Evaluation of a Dual Adaptive Remote Microphone System

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ABSTRACT

Standard adaptive remote microphone (RM) systems increase progressively the RM gain when the ambient noise level exceeds an activation threshold in dB SPL. A dual adaptive RM system increases progressively the RM gain in moderate noise but reaches a plateau in RM gain after a 10-dB increase. Further increases in ambient noise result in a reduction in hearing aid gain with the goal of improving the SNR for the RM signal while also optimizing listening comfort. The objective of this study was to compare speech recognition and subjective preferences of school-age children using hearing aids with standard adaptive and dual adaptive RM systems in a classroom environment.

Twenty-five children with bilateral, mild to moderately severe hearing loss participated in the repeated measures design to evaluate device differences. Sentence recognition in quiet and in noise and subjective preferences were assessed in a classroom setting with each technology in several conditions to simulate common classroom listening situations. Performance was also assessed in the hearing aid only condition (i.e., no RM).

Significantly improved speech recognition was found with both RM systems compared to the no-RM condition. No significant differences in speech recognition in quiet or in noise were observed between the RM systems in any test conditions. Additionally, participants did not report a significant preference for either RM system, although there was a non-significant trend toward an overall preference for the dual adaptive system in traditional classroom settings.

INTRODUCTION

Children with hearing loss experience difficulty with speech recognition in noisy (at signal-to-noise ratios [SNRs] commonly encountered in classroom settings) and reverberant situations and when the speech signal of interest originates from a distance (i.e., more than a meter; Crandell, 1991; 1992; 1993; Crandell and Bess, 1986; Finitzo-Hieber and Tillman, 1978; Nabelek and Nabelek, 1985; Wolfe et al., 2013a). For instance, Bradley (1986) noted that school-age children who have normal hearing require at least a 15 dB SNR for optimal speech perception. However, Sato and Bradley (2008) reported that only 2% of classrooms they evaluated were found to have an SNR of 15 dB or better.

Remote microphone (RM) systems are the most effective technology to improve speech perception in noise for children who use hearing aids, cochlear implant, bone conduction devices, or ear-level radio receivers (Hawkins, 1984; Ricketts, 2001; Wolfe et al, 2013a; Zanin & Rance, 2016; Iglehart, 2020). A RM system includes a microphone worn by the primary talker (e.g., the classroom teacher) to capture the speech and a radio transmitter to deliver a wireless signal to the child's receivers coupled to the hearing aids. The use of RM systems can improve speech recognition by at least 30 to 60 percentage points (Hawkins, 1984; Lewis et al, 2004; Madell, 1992; Wolfe et al., 2009; Wolfe et al., 2013a; 2013b) at signal-to-noise ratios (SNRs) encountered in daily listening situations. (e.g., 0 to +5 dB SNR; Larsen & Davis, 2008; Crukley, Scollie, & Parsa, 2011; Pearsons et al., 1977). Of note, Larson and Davis (2008) found that classroom SNRs commonly ranged from +1 to +6 dB in the classrooms they evaluated.

RM system gain determines the strength of the signal delivered from the RM receiver to the user's hearing aids. Fixed-gain systems do not vary the strength of the signal delivered from the radio receiver to the user's personal hearing technology as a function of the ambient noise level (e.g., 10 dB gain from the RM receiver in all noise levels). In contrast, adaptive RM systems automatically increase receiver gain as the ambient noise level in the environment increases. Figure 1a provides an example of an adaptive system that provides 0 dB of gain from the RM receiver for ambient noise level inputs less than 57 dB SPL. As shown in Figure 1a, the gain delivered from the RM receiver to the hearing aid increases by 1 dB for every 1-dB increase in ambient noise level in excess of 57 dB SPL (i.e., the activation threshold of the adaptive feature) up to a total increase of 20 dB (when available headroom allows). The adaptive RM system (i.e., standard adaptive) uses the adaptive gain increases to maintain a favorable SNR in environments with moderate- to high-level noise. Research has shown that adaptive systems provide better speech recognition for older children and adults with hearing aids and cochlear implants in moderate- to high-level noise when compared to fixed-gain RM systems (Thibodeau, 2010; 2014; Wolfe et al., 2009; Wolfe, Morais, Schafer et al., 2013b). Of note, a standard adaptive RM system monitors ambient noise levels at the RM and makes adaptive gain changes according to the measured noise level.

Although receiver gain increases in high noise levels may result in a more favorable SNR and improved speech recognition, the aided output level could be too loud to allow for comfortable listening levels in high-level noise environments. Children often prefer lower loudness levels when listening in noise (Scollie et al., 2010; Crukley & Scollie, 2014). Moreover, Lewis and Eiten (2004) found children preferred lower RM gain levels in high-noise environments.

Figure 1b provides a visual description of an adaptive-gain RM system (i.e., dual adaptive) that aims to provide a favorable SNR at moderate to high noise levels while also maintaining acceptable loudness and listening comfort. As shown in Figure 1b, the RM receiver gain increases by 1 dB for every 1-dB increase in noise above 57 dB SPL for a total adaptive RM gain increase of 10 dB. Once the noise exceeds 67 dB SPL, the adaptive gain of the RM system plateaus, and each additional 1-dB increase in noise results in a 1-dB decrease in the gain applied to the hearing aid microphone. Reducing hearing aid gain improves the relative SNR because the RM gain is not reduced. The reduced gain to the hearing aid microphone will result in decreased aided output, lessening the likelihood of loudness discomfort at high noise levels. In contrast to a standard adaptive RM, the dual adaptive RM used in this study monitors the ambient noise at the hearing aid microphone rather than the RM and makes adaptive changes according to the noise level.

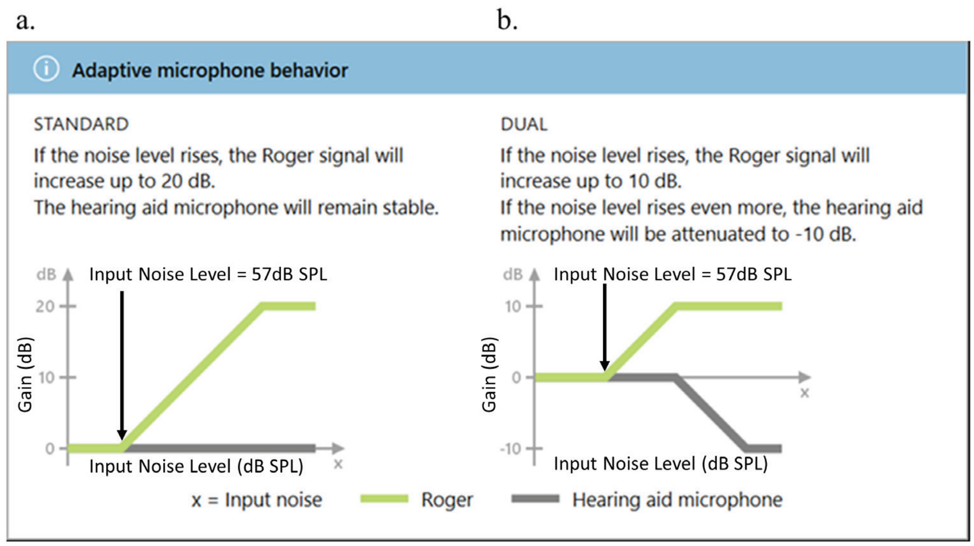


Figure 1. Adaptive RM behavior for the standard (left) and dual adaptive (right) RM systems (used with permission from Phonak, LLC.).

There are no published studies that identify the potential benefits and limitations school-age children experience with the use of standard adaptive versus dual adaptive RM systems in classroom settings. The primary objectives of this study were to compare the standard adaptive and dual adaptive RM systems across multiple domains in school-age children with hearing loss see Table 1 for characteristics pertaining to study participants including:

1. Speech recognition in quiet and in noise in a variety of classroom listening situations ((i.e., speech from the front in quiet and noise; hearing a peer from a distance in noise; asymmetrical listening arrangements; see Table 2 for description).
2. Subjective preferences for each type of RM system in a variety of classroom listening situations (see Tables 2, 3, and 4 for description).

METHOD

Participants

Twenty-five children, ages 9 to 17 years (M=14.1; SD= 2.1), with bilateral mild to moderately severe sensorineural hearing loss participated in this study. Average four-frequency (500, 1000, 2000, 4000 Hz) pure tone average (PTA) was 55.4 dB HL (SD=12.8) for the right ear and 55.1 dB HL (SD=10.1) for the left ear with a range of 37.5 to 70 dB HL across ears. All used digital behind-the-ear (BTE) or receiver-in-the-canal (RIC) hearing aids prior to recruitment into the study, and 21 out of 25 children had previously used a standard RM system prior to participation in this study. .

Table 1. Participant Ages and Four-Frequency Pure Tone Averages

Participant	Age (yrs)	Left PTA	Right PTA
1	17	60	68
2	18	61	63
3	12	63	59
4	16	51	49
5	12	46	49
6	13	50	50
7	9	53	41
8	10	43	46
9	15	70	66
10	10	44	40
11	16	73	58
12	13	61	75
13	15	61	55
14	13	40	39
15	15	49	48
16	11	46	48
17	13	48	46
18	14	38	38
19	14	56	53
20	13	59	65
21	14	68	80
22	17	68	80
23	15	56	54
24	16	70	74
25	13	46	45
Average	13.8	55	55
SD	2.3	10	13

PTA=four-frequency pure tone average; SD=standard deviation.

Technology

All participants were fitted with digital BTE hearing aids for use in this study. Children who used BTE hearing aids with earmolds were fitted with Phonak Sky Marvel M90 BTE hearing aids coupled to their personal earmolds, whereas children who used BTE hearing aids with a receiver-in-the-canal (RIC) were fitted with Phonak Audéo Marvel M90 BTE hearing aids coupled to RICs with custom shells. The output (dB SPL) of each hearing aid was measured with use of the Audioscan Verifit 2 hearing aid analyzer. Real-ear-to-coupler difference (RECD) measures were completed, and the output of each hearing aid was matched (within +/-5 dB) to Desired Sensation Level (DSL) 5.0 prescriptive targets for children for the Audioscan Standard Speech Signal presented at 55, 65, and 75 dB SPL. The maximum output of the hearing aid was also matched to DSL 5.0 targets for a 90 dB SPL swept pure tone. The study hearing aid advanced technology features were all set with the age-appropriate pediatric default settings (i.e., feedback cancellation, noise reduction, and adaptive directionality were all enabled) in order to allow for an evaluation of performance reflective of how the hearing aids would function in realistic wearing conditions.

Transparency of the RM system was evaluated with use of a portion of the RM verification protocol recommended in the American Academy of Audiology Clinical Practice Guideline for the fitting of Remote Microphone Systems (AAA, 2011). The standard speech signal was first delivered at 65 dB SPL to the hearing aid microphone while the hearing aid was connected to the coupler inside the Audioscan Verifit 2 hearing aid analyzer test box. In this condition, the hearing aid was set to the manufacturer's default auto-RM-enabled program, and the RM was muted and set to the manufacturer's verification mode. The hearing aid output was saved on the display of the hearing aid analyzer. Then, the same 65 dB SPL standard speech signal was presented to the RM which was unmuted and placed in the test box within 2 mm of the reference microphone used during the initial measurement made with the signal delivered to the hearing aid. The HA was still connected to the coupler but outside the test box, and the hearing aid output was matched within 2 dB of the average at 750, 1000, and 2000 Hz to the output that occurred when the signal was presented to the hearing aid microphone. These measures were completed with both the standard and dual adaptive RM systems.

Test Conditions and Procedures

All assessments were conducted in a 24'10'' (7.57 meters) by 20'4'' (6.2 meters) by 9' (2.74 meters) unoccupied classroom (see Figures 2-4 for a visual description of the classroom and study set-up) with an ambient noise level of approximately 32 dBA as measured with a Larson Davis Soundtrack LXT Type 2 sound level meter. The reverberation time required for 60 dB attenuation (RT60) was .4 seconds (averaged across frequency), which is similar to a typical classroom (Knecht et al., 2002; Sato & Bradley, 2008; Crukley et al., 2011). Speech recognition with the standard adaptive and dual adaptive RM systems was assessed in the following classroom listening situations:

Traditional Remote Microphone Condition. To simulate the teacher talking in the front of the classroom, speech was presented from a loudspeaker at 0 degrees azimuth, 8 feet, six inches (2.59 meters) from the participant, who was seated in the front half of the classroom (Figure 2). Classroom noise (see Schafer & Thibodeau, 2004) was presented from four loudspeakers placed near the corners of the classroom. Sentence recognition was evaluated with the standard adaptive and dual adaptive RM system in each of the following conditions with signal and noise levels measured at the location of the subject (of note, signal and noise levels were selected to allow for an assessment of the two RM technologies in conditions in which differences would and not be expected based on the differences in adaptive gain changes made by each technology):

- In quiet with speech level at 65 dBA
- Speech at 69 dBA and noise at 65 dBA (+4 dB SNR)
- Speech at 72 dBA and noise at 70 dBA (+2 dB SNR)
- Speech at 74 dBA and noise at 74 dBA (0 dB SNR)
- Speech at 73 dBA and noise at 75 dBA (-2 dB SNR)

A Phonak Roger Touchscreen RM was positioned 6 inches (15.24 centimeters) directly below the center of the loudspeaker used to present the AzBio sentences. The Roger Touchscreen RM was used for both the standard adaptive and dual adaptive systems. A research version of Phonak Target software was used to program the hearing aids in either standard adaptive mode or dual adaptive mode. The hearing aids were coded by a research audiologist, who kept track of which hearing aid program was the standard adaptive and which was the dual adaptive mode. Consequently, the research assistant who completed testing was unaware of the technology condition that was being used for each trial.

For the "traditional RM condition," the classroom noise level was identical at the location of the participant as well as the RM. One full list (20 sentences) of AzBio sentences (Spahr et al., 2012) was presented in each condition. Sentence recognition was also evaluated in the hearing aid alone condition (i.e., no RM) in the 4 dB SNR conditions. For all speech recognition assessments completed in this study, the participants were asked to repeat the entire sentence, and performance was scored by determining the number of words in percent correct that the participant could correctly repeat from the total words presented. An audiology research assistant scored the child's responses. Of note, the participants wore a RM during testing, and the research assistant wore a RM receiver to allow the assistant to hear the participants' responses in the presence of the competing noise. Also of note, the audiologist and participant were blinded to the technology conditions that were being studied in each trial.

AzBio sentences were selected as the speech recognition material of choice for the current study to avoid ceiling effects that may have been more likely to occur with other sentence materials (Gifford et al., 2008). AzBio sentence materials have been shown to be suitable for the evaluation of speech recognition in noise with a group of children similar in age and audiometric characteristics to the children in the current study (Wolfe et al., 2017). A total of 33 AzBio sentence lists were used in this study, and the lists were never repeated during assessment with each subject. The use of each of these sentence lists was counter-balanced across subjects and test conditions to avoid a list order or difficulty effect. Additionally, all technology conditions and listening conditions were counter-balanced across subjects to avoid order effects.

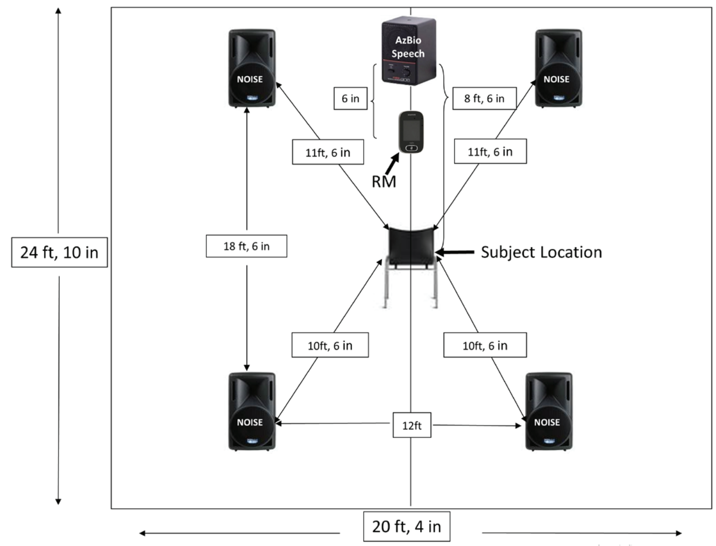


Figure 2. Classroom arrangement for the traditional RM conditions.

Traditional Peer Condition. To simulate listening to a peer in the classroom, participants were tested at a +4 SNR with the standard adaptive and dual adaptive RM systems. Speech was presented at 69 dBA (measured at the subject location) from a loudspeaker in front-center of the classroom at 0 degrees azimuth, 3 feet (.91 meters) from the participant, who was seated in the front half of the classroom (Figure 3). Classroom noise (Schafer & Thibodeau, 2004) at 65 dBA (measured at the subject location) was presented from four loudspeakers near the corners of the classroom. One full list of AzBio sentences was used to evaluate sentence recognition in noise. Of note, the RM was active during the peer condition in order to keep it in the RM mode, but it was located 15 feet (4.57 meters) away from the loudspeaker used to present the speech signal, and the directional microphone of the RM system was positioned away from the speech loudspeaker. As a result, the participants primarily received the speech signal from the hearing aid microphone.

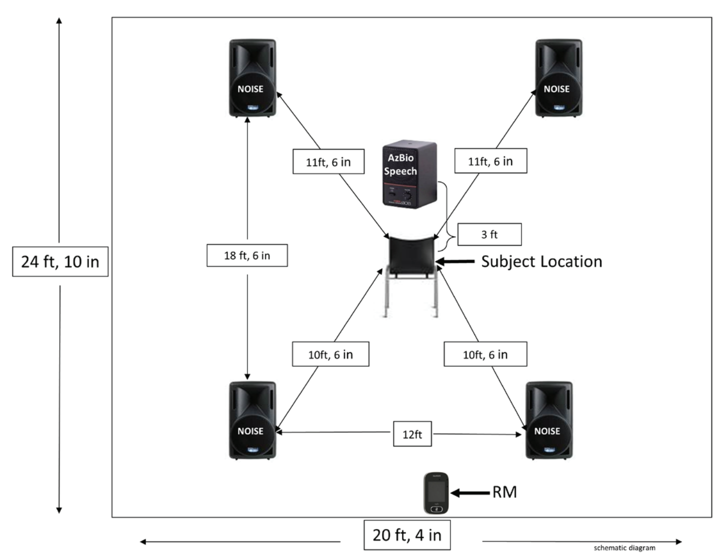


Figure 3. Classroom arrangement for the traditional peer condition.

Asymmetrical Remote Microphone Condition/Noise Front. As previously discussed, the standard adaptive RM system evaluated in the current study monitors the ambient noise level at the RM, whereas the dual adaptive RM monitors ambient noise levels at the hearing aid microphone. To determine whether the differences in the site at which ambient noise level is monitored for the two RM systems under study, speech recognition and subjective preference were evaluated in two "asymmetrical conditions," one in which the noise originated from the front of the classroom where the RM located and another which the noise originated from the back of the classroom where the participant and hearing aids were located.

In the "asymmetrical RM/noise front condition," the speech loudspeaker was located at the front-center of the classroom at 0 degrees azimuth, 18 feet, six inches (5.64 meters) from the participant who was seated in the back of the classroom (Figure 4a). Classroom noise (Schafer & Thibodeau, 2004) was presented from two loudspeakers near the front corners of the classroom (Figure 4a). Sentence recognition was evaluated with the standard adaptive and dual adaptive RM systems in each of the following conditions at the location of the participant:

- Speech at 72 dBA and noise at 70 dBA (+2 dB SNR)
- Speech at 74 dBA and noise at 72 dBA (+2 dB SNR)

Of note, in the asymmetrical RM condition with noise at the front of the classroom, the speech level was measured at the location of the subject, whereas the noise level was measured at the location of the RM. Also of note, the noise level at the location of the participant was 59 dBA and 61 dBA, respectively, for the first and second conditions listed above. One full list (20 sentences) of AzBio sentences (Spahr et al., 2012) was presented in each condition. Sentence recognition was also evaluated in each adaptive RM condition and also in the hearing aid alone condition (i.e., no RM). The asymmetrical noise-front condition of this study was intended to simulate an exceptional and possibly unlikely listening situation in which the level of the competing noise is substantially higher at the RM relative to the hearing aid microphone (i.e., the dual adaptive would not provide a reduction in hearing aid gain because of the relatively low noise level at the hearing aid microphone, and as a result, the participant may be more likely to prefer the increased gain from the standard adaptive system).

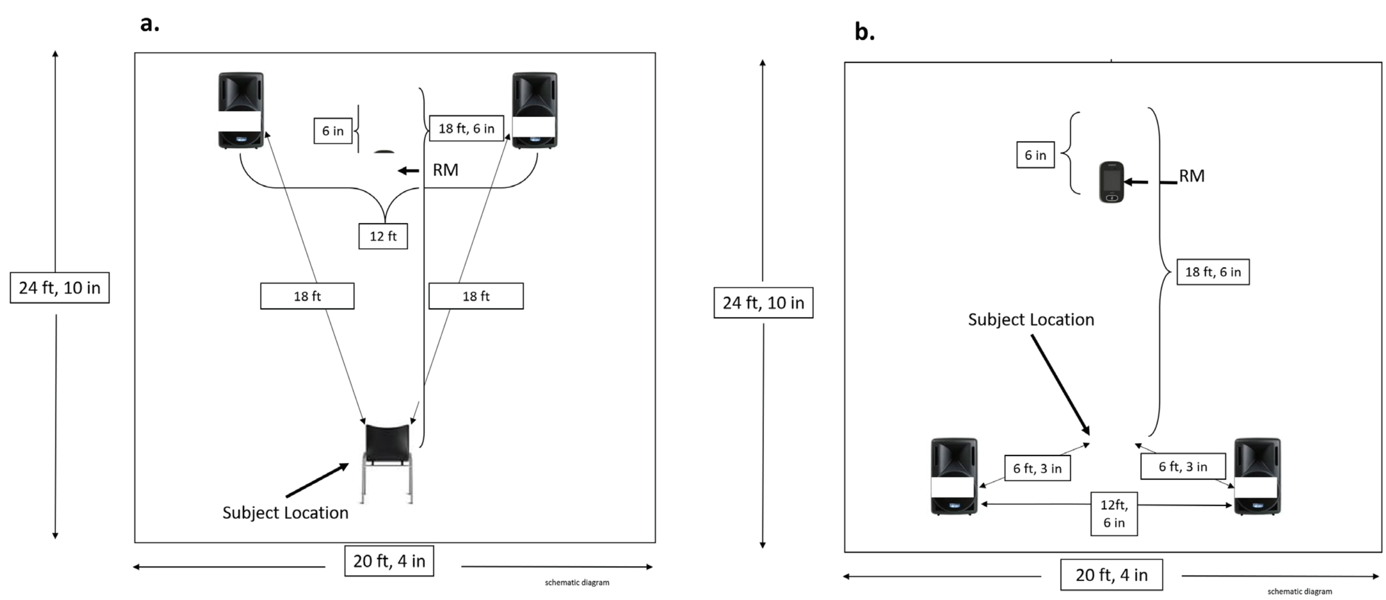


Figure 4. Classroom arrangement for the asymmetrical conditions with noise from the front (a) or back (b).

Asymmetrical Remote Microphone Condition/Noise Back. In the "asymmetrical RM/noise back condition," the speech loudspeaker was located at the front-center of the classroom at 0 degrees azimuth, 18 feet, six inches (5.64 meters) from the participant, who was seated in the back of the classroom (Figure 4b). Classroom noise (Schafer & Thibodeau, 2004) was presented from two loudspeakers near the back corners of the classroom (Figure 4b).

Sentence recognition was evaluated with use of the standard adaptive and dual adaptive RM systems in each of the following conditions with the signals at the location of the participant:

- Speech at 72 dBA and noise at 70 dBA (+2 dB SNR)
- Speech at 74 dBA and noise at 72 dBA (+2 dB SNR)

Of note, in the asymmetrical RM condition with noise presented from the back of the classroom, the speech and noise levels were each measured at the location of the subject. Also of note, the noise level at the location of the RM was 59 dBA and 61 dBA, respectively, for the first and second conditions listed above. Sentence recognition was also evaluated in each adaptive RM condition and also in the hearing aid alone condition (i.e., no RM). The asymmetrical noise-back condition of this study was intended to simulate an exceptional and possibly unlikely listening situation in which the level of the competing noise is substantially higher at the hearing aid microphone relative to the RM (i.e., the noise level would be lower at the RM).

A summary of each speech recognition test condition along with research questions and statistical analyses are provided in Table 2.

Table 2. Summary of Research Questions, Test Conditions in dBA, and Statistical Comparisons

Research Question	Remote Microphone System Conditions	Signal Level or SNR	Statistical Analysis
System differences in quiet with speech from the front?	Standard Traditional vs. Dual Traditional	Speech: 65 dBA	One-way RM ANOVA
System differences in noise with speech from the front?	Standard Traditional vs. Dual Traditional	1. Speech: 65/ Noise: 65 2. Speech: 69/ Noise: 65 3. Speech: 72/ Noise: 70* 4. Speech: 73/ Noise: 75*	Two-way RM ANOVA with independent variables of device and SNR
System difference for a peer from a distance in noise?	Standard Traditional vs. Dual Traditional	Speech: 69/ Noise: 65*	One-way RM ANOVA
Differences across systems and with no device for asymmetrical listening arrangements?	Standard Traditional vs. Dual Traditional vs. No Device	1. Speech: 72 Front/ Noise: 70* 2. Speech: 72 Back/ Noise: 70* 3. Speech: 74 Front/ Noise: 72* 4. Speech: 74 Back/ Noise: 72*	Three-way RM ANOVA with independent variables of device, speaker location (front/back), and SNR

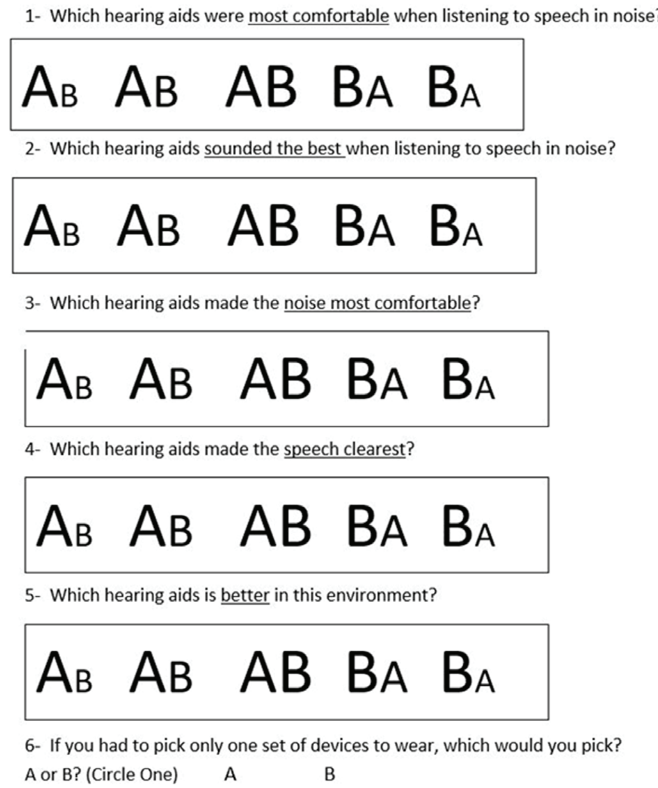
Note. The asterisks represent conditions in which subjective preferences for the RM systems were recorded. RM ANOVA=repeated measures analysis of variance; SNR=signal-to-noise ratio.

Assessment of Subjective Preference of Remote Microphone System. The participants' subjective preferences between standard adaptive and dual adaptive RM systems were evaluated with A/B comparison assessments. Subjective preferences were evaluated in several of the classroom listening situations indicated with asterisk in Table 2, and the questions asked in each noise condition are provided in Table 3. Table 4 also contains the signal and noise levels used for each of the conditions in which the A/B comparison tests were completed. Of note, the set-up for the classroom listening situations (e.g., traditional RM condition, traditional peer condition, asymmetrical front and back conditions) for the A/B comparison assessments were identical to the set-up for the speech recognition assessments described above. The levels of the signal of interest and classroom noise were calibrated using the same procedures as described for the speech recognition assessment portion of this study.

Table 3. Questions in the A/B Rating Scale for Each Noise Condition

1. Which hearing aids were the most comfortable when listening to speech in noise?
2. Which hearing aids sounded the best when listening to speech in noise?
3. Which hearing aids made the noise most comfortable?
4. Which hearing aids made the speech clearest?
5. Which hearing aid would you choose to use in this environment?
6. If you had to pick only one set of devices to wear, which would you pick?

For the A/B comparison test, the participants listened to an audio excerpt from the children's book, Tales of a Fourth Grade Nothing, in classroom noise (Schafer & Thibodeau, 2004). Participants indicated their preference for a particular RM system by selecting from five options shown on Figure 5. The technology conditions were double-blinded making participants and examiners unaware of the RM technology in use during the A/B comparison testing. To prevent order effects, RM technologies were counter-balanced across listeners for the A/B comparison testing.


1- Which hearing aids were most comfortable when listening to speech in noise?

AB AB AB BA BA

2- Which hearing aids sounded the best when listening to speech in noise?

AB AB AB BA BA

3- Which hearing aids made the noise most comfortable?

AB AB AB BA BA

4- Which hearing aids made the speech clearest?

AB AB AB BA BA

5- Which hearing aids is better in this environment?

AB AB AB BA BA

6- If you had to pick only one set of devices to wear, which would you pick?

A or B? (Circle One) A B

Figure 5. Form used during A/B subjective ratings. AB= A is a lot better; AB= A is a little better; AB= A is the same as B; BA= B is a little better; BA= B is a lot better.

RESULTS

Quiet and Noise with Speech from the Front

Average performance in quiet and noise with the two systems is shown in Figure 6. In addition to these data, average speech recognition with no RM system was 57.8 (SD=15.5) with speech at 69 dB SPL and noise at 65 dB SPL. A one-way repeated measures analysis of variance (RM ANOVA) on performance in quiet with speech from the front revealed no significant difference between the standard and dual systems ($F [1, 49] = 0.13$, $p = 0.72$).

The two-way RM ANOVA used to analyze performance in the noise conditions with speech from the front suggested no significant main effect of system ($F [1, 198] = 0.13$, $p = 0.72$), a significant main effect of SNR ($F [3, 196] = 6.8$, $p < .001$), and no interaction effect between system and SNR ($F [1, 198] = 1.6$, $p = 0.19$). A post-hoc Bonferroni Multiple Comparison Test on the significant effect of SNR suggested significantly poorer performance in the condition with speech at 73 dBA and noise at 75 dBA when compared to all other SNRs.

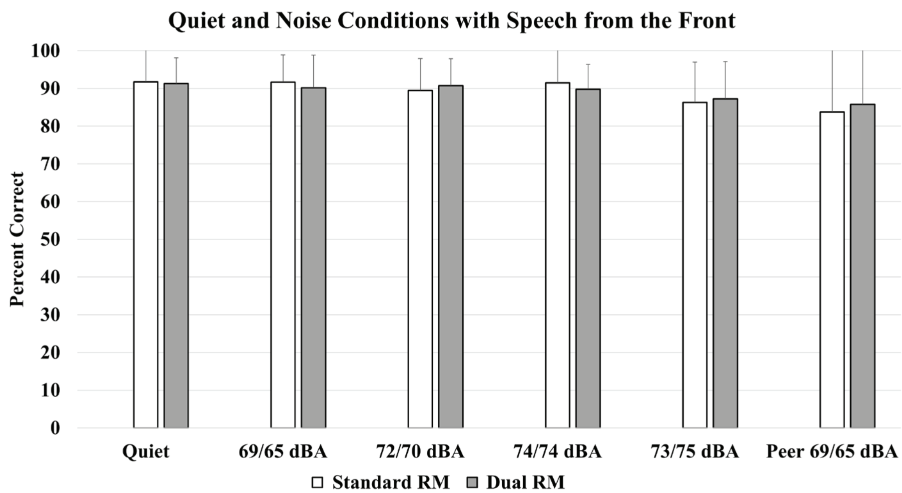


Figure 6. Average performance in the traditional RM conditions. Vertical lines represent one standard deviation.

Listening to Peers

Average performance for listening to a peer in background noise is also shown in Figure 6. The one-way RM ANOVA showed no significant difference between systems (F [1, 49] = 1.3, p = .0.27).

Asymmetrical Listening Arrangements

Results from the asymmetrical listening conditions is shown in Figure 7. The three-factor RM ANOVA to examine the effect of system, noise location, and signal levels suggested a significant main effect of system (F [1, 299] = 455.8, p =< 0.0001), significant main effect of noise location (F [1, 299] = 19.8, p < 0.001), and significant main effect of signal level (F [1, 299] = 9.8, p < 0.01). In addition, one significant interaction effect was found between system and noise location (F [2, 298] = 9.5, p < 0.001). Post-hoc analysis of the significant main effects found that both the standard and dual systems resulted in significantly better performance than with the hearing aid alone (i.e., no RM), the location of the noise to the rear resulted in significantly better performance than when noise was near the front, and the condition with speech at 74 dBA and noise at 72 dBA provided significantly better performance than when speech was at 72 dBA and noise at 70 dBA. Post-hoc analysis of the significant interaction effect showed significantly poorer performance with no device as compared to all device conditions, and the no-device condition with noise from the rear was significantly better than the no-device condition with noise from the front.

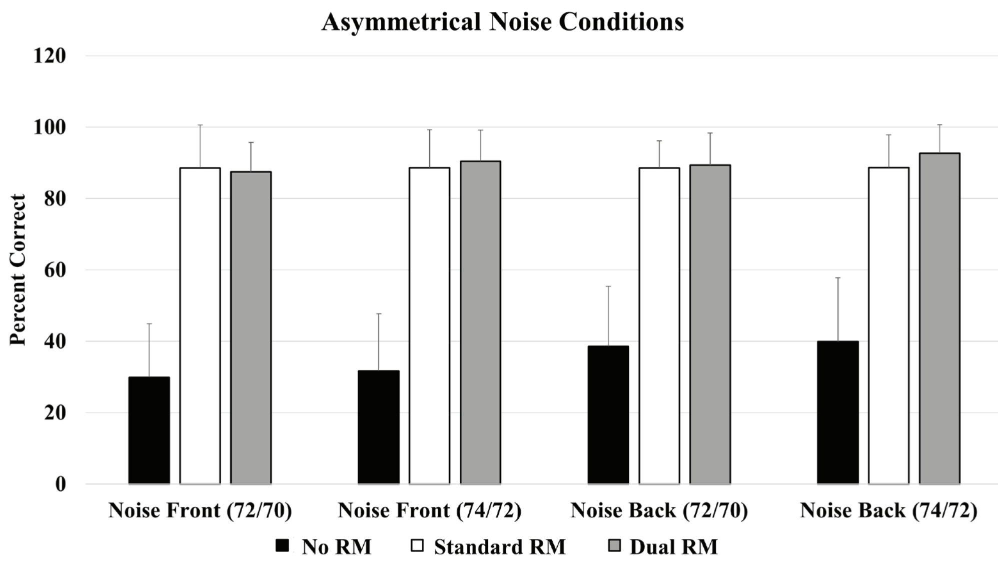


Figure 7. Average performance in the asymmetrical RM conditions. Vertical lines represent one standard deviation.

Subjective Ratings

Descriptive statistics are used in Table 4 to provide the individual A/B comparison ratings for 24 participants. Of note, one subject did not complete the A/B comparison testing portion of the study due to a scheduling conflict. One aspect of these data was analyzed statistically with the sign test (Dixon & Mood, 1946) (i.e., Only had to pick one). Based on these analyses, there was no significant difference in preferences between RM technologies (Table 4).

Table 4. Preference Ratings on the A/B Comparison Test for the Standard and Dual RM Systems with the Numbers Representing the Total Number of Subjects (N=24) Who Selected Each Rating in a Particular Condition.

Test Condition	System Preferences	Comfort	Sounded the best	Noise most comfortable	Speech clearest	Choose to use	Only had to pick one
Speech from the front: +2 dB SNR - Speech 72/ Noise 70 dBA	-Standard++ -Standard+ -None -Dual+ -Dual++	3 5 1 11 4	3 4 5 6 6	5 7 5 3 4	5 4 2 7 6	6 2 0 9 7	Standard: 9 Dual: 15 p = *.31*
Speech from the front: -2 dB SNR - Speech 73/Noise 75 dBA	-Standard++ -Standard+ -None -Dual+ -Dual++	4 4 8 5 3	4 4 6 5 5	4 5 3 7 5	4 4 4 7 5	3 6 2 7 6	Standard: 9 Dual: 15 p = *0.31*
Peer from a distance: +4 dB SNR – Speech 69/Noise 65 dBA	-Standard++ -Standard+ -None -Dual+ -Dual++	5 1 6 7 5	2 4 6 7 5	4 2 5 9 4	2 4 8 8 2	3 4 2 8 7	Standard: 7 Dual: 17 p = *0.06*
Asymmetrical: Speech: +2 dB SNR - 72 dBA Front/ Noise: 70 dBA	-Standard++ -Standard+ -None -Dual+ -Dual++	4 6 4 6 4	8 5 3 6 2	3 8 4 4 5	3 6 8 3 4	5 7 1 6 5	Standard: 13 Dual: 11 p = *0.84*
Asymmetrical: Speech: +2 dB SNR - 72 dBA Back/ Noise: 70 dBA	-Standard++ -Standard+ -None -Dual+ -Dual++	5 3 8 6 2	2 4 6 10 2	2 7 6 7 2	1 6 5 5 7	3 8 2 6 5	Standard: 11 Dual: 13 *p = 0.84*
Asymmetrical: Speech: +2 dB SNR -74 dBA Front/ Noise: 72 dBA	-Standard++ -Standard+ -None -Dual+ -Dual++	3 6 6 5 4	3 6 6 5 4	5 2 6 6 5	2 5 9 4 4	1 11 1 6 5	Standard: 12 Dual: 12 p = *1.0*
Asymmetrical: Speech: + 2 dB SNR - 74 dBA Back/ Noise: 72	-Standard++ -Standard+ -None -Dual+ -Dual++	6 7 6 1 4	2 5 6 6 5	5 7 2 6 4	3 3 9 6 3	3 8 4 4 5	Standard: 11 Dual: 13 p = *0.84*

Note. The *p* value in the final column is from a sign test (Dixon & Mood, 1946). SNR=signal-to-noise ratio. Standard++ and Standard +=standard is a lot or a little better, respectively; None=no perceived difference between systems; Dual + and Dual++=dial is a little or a lot better, respectively.

DISCUSSION

Speech Recognition in Quiet and in Noise

Speech recognition in quiet and commonly encountered classroom SNRs approached ceiling levels with both RM technologies. In addition, both RM systems significantly improved speech recognition in noise compared to the hearing aid only (i.e., no RM) condition. No significant differences were found between systems in quiet or in noise in the traditional classroom setting or the asymmetrical conditions. Benefit from the systems was similar to benefits observed in previous studies of digital adaptive RM systems (Thibodeau, 2014; Wolfe et al., 2013).

The asymmetrical conditions simulated extreme situations where the noise level was higher at either the location of the talker (e.g., noise front) or the listener (e.g., noise back). These extreme situations aimed to assess potential difference between the standard adaptive RM system, which monitors noise at the RM, and the dual adaptive system, which monitors noise at the hearing aid microphone. However, this arrangement did not yield significant system differences, likely because each system provided similar improvements through different approaches. The standard adaptive RM system increases RM gain with each dB of increased noise exceeding the activation threshold up to 20 dB of gain. Conversely, the dual adaptive RM system uses a combined approach by increasing RM gain by 10 dB after the activation threshold and, then, decreasing the gain of the hearing aid microphone by 1 dB for each subsequent increase in noise up to a maximum reduction of 10 dB. In short, each system provided up to a 20 dB improvement in the SNR relative to a fixed-gain RM system. The dual adaptive RM system allowed for similar improvement in the SNR and speech recognition in noise with lower requisite hearing aid output levels when compared to the standard adaptive RM system.

Subjective Preferences

There were no significant differences in subjective preferences between the two RM systems (Table 4). Subjective preference may be related to the similar speech recognition performance obtained with the two systems. Of note, there was a non-significant trend toward an overall preference for the dual adaptive system in traditional classroom settings.

Prior to the study, most of the participants used the standard adaptive RM system. Their familiarity with the standard adaptive RM system may have biased their initial impression of the dual adaptive RM system. Additional experience with the dual adaptive RM system could have yielded different preferences.

Anecdotally, a subset of the participants offered comments to explain their preferences. In general, the children who preferred the standard adaptive RM system commented that it made the speech louder, whereas the children who preferred the dual adaptive RM system commented that the speech was more comfortable, natural, and easier to understand. Scollie et al. (2010) found that children expressed a strong preference toward the use of multiple programs, one of which provided more gain for low-level sounds in quieter environments and another which provided less gain for higher-level noise environments. It is possible that some children may prefer to select between standard and dual adaptive RM systems depending upon the acoustics of their environment. It is also possible that some children may prefer higher output levels and maybe more inclined to select the standard adaptive RM system, whereas other children may prefer to listen at lower output levels and may be more inclined to select the dual adaptive RM system. Of note, listening at lower output levels with the dual adaptive RM system may reduce listening fatigue for some children (Hicks & Tharpe, 2002; Picou et al., 2019). Further research is needed to determine whether the inclusion of additional measures, such as the most comfortable level (MCL), the uncomfortable loudness level (UCL), the Acceptable Noise Level (Nabalek et al., 2006), etc., may assist in the selection of the ideal adaptive RM system for each child. Additional research is also needed to determine whether children who are new to RM systems and children with severe hearing loss have a preference between standard and dual RM systems. Finally, it is worth noting that use of the dual adaptive RM system allows for similar speech recognition at a lower output level, which may decrease the possibility for noise-induced hearing loss from the use of high-level amplification.

CONCLUSION

Use of the adaptive RM systems evaluated in this study improved speech recognition in noise compared to the hearing aid only (no RM) condition. There were no statistically significant differences in speech recognition in quiet or in noise between the standard adaptive and dual adaptive RM systems. Additionally, there was no clear difference in subjective preference for the two adaptive RM systems when school-age children with hearing loss were evaluated in simulated classroom listening situations, although a trend did exist for children to prefer the use of the dual adaptive system.

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