

Speech perception in noise in normally hearing children: does binaural frequency modulated fitting provide more benefit than monaural frequency modulated fitting?

Siti Zamratol-Mai Sarah Mukari, Cila Umat, Ummu Athiyah Abdul Razak

Department of Audiology & Speech Sciences, Faculty of Allied Health Sciences, Universiti Kebangsaan Malaysia

Abstract

The aim of the present study was to compare the benefit of monaural versus binaural ear-level frequency modulated (FM) fitting on speech perception in noise in children with normal hearing. Reception threshold for sentences (RTS) was measured in no-FM, monaural FM, and binaural FM conditions in 22 normally developing children with bilateral normal hearing, aged 8 to 9 years old. Data were gathered using the Pediatric Malay Hearing in Noise Test (P-MyHINT) with speech presented from front and multi-talker babble presented from 90°, 180°, 270° azimuths in a sound treated booth. The results revealed that the use of either monaural or binaural ear level FM receivers provided significantly better mean RTSs than the no-FM condition

($P < 0.001$). However, binaural FM did not produce a significantly greater benefit in mean RTS than monaural fitting. The benefit of binaural over monaural FM varies across individuals; while binaural fitting provided better RTSs in about 50% of study subjects, there were those in whom binaural fitting resulted in either deterioration or no additional improvement compared to monaural FM fitting.

The present study suggests that the use of monaural ear-level FM receivers in children with normal hearing might provide similar benefit as binaural use. Individual subjects' variations of binaural FM benefit over monaural FM suggests that the decision to employ monaural or binaural fitting should be individualized. It should be noted however, that the current study recruits typically developing normal hearing children. Future studies involving normal hearing children with high risk of having difficulty listening in noise is indicated to see if similar findings are obtained.

Correspondence: Siti Zamratol-Mai Sarah Mukari, Department of Audiology & Speech Sciences, Faculty of Allied Health Sciences, Universiti Kebangsaan Malaysia, Jalan Raja Muda Abdul Aziz 50300 Kuala Lumpur, Malaysia. Tel. +603 26914230. E-mail: zamratol@hotmail.com

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Introduction

Over the years, the application of the frequency modulated (FM) system has been expanded to include children with normal hearing, specifically, those who have special listening needs.¹ Normal hearing children who may benefit from an FM system include those with reading delays,² attention deficit disorders,³ auditory processing disorders,⁴ and children in classrooms in which teaching is not in their primary language.⁵

The classroom is a rich acoustic environment and effective communication is important for classroom learning. Several acoustic parameters are of importance when addressing classroom acoustics: signal-to-noise ratio (SNR), speaker-listener distance and reverberation. The American National Standard Institute (ANSI) standard for classroom acoustics ANSI S12.60-2002⁶ specifies maximum sound levels of 35dBA for unoccupied classrooms and a maximum reverberation time of 0.6 sec to ensure an optimum learning environment. However, various studies have shown that classroom noise levels are higher than specified by the ANSI standard.⁷ Crandell and Smaldino⁷ summarized some earlier studies which measured the classroom noise levels in unoccupied and occupied rooms. The levels measured varied from 41 dBA in an unoccupied room to 68 dBA in occupied rooms.

The issue with distance relative to the sound source is closely related to reverberation. At a relatively close distance from the source, the signal originating from the sound source is less affected by reverberation. Therefore, students who sit closer to the teacher have the advantage of receiving relatively strong speech signals from the teacher compared to those who sit farther away. As the signal's strength reduces with distance, reverberation becomes stronger than the speech signal of interest. Masking of speech by reverberation occurs, leading to difficulties to understand speech.^{7,8}

Besides its detrimental impact on listening, poor classroom acoustics are also known to affect learning and literacy skills of even normal hearing children.^{9,10} Good classroom acoustics provide the opportunity for a child to have better access to auditory information, which forms the basis for developing literacy and academic skills. Clear speech signals gained from good SNRs ensure provision of accurate and reliable auditory information, which is the crucial first step in the learning chain.

One of the ways to address the issue of classroom acoustics is to use the personal FM system. The FM system helps minimize the problem with distance (and thus, reverberation) and improves the SNR. For instance, a study which examined the speech perception benefits in noise from body-worn and binaural ear-level FM systems in a group of normally hearing young adults indicated that either of the FM configurations provided an SNR benefit of 8 to 9 dB.¹¹ Another study on a group of children with attention deficit disorders and those suspected of having auditory processing disorders (APDs) revealed that improved performance on specific auditory perceptual tasks was observed following one year of use of a personal FM system.³

Although several studies have reported the benefits of ear-level FM systems^{11,12} the benefits of fitting binaural over monaural FM on speech recognition in noise in normal hearing children have not been reported in the literature. One previous study compared the benefit of monaural and binaural ear-level FM fitting in a group of children with some degree of hearing loss using Hearing in Noise Test for Children (C-HINT).¹² The results revealed that while both monaural and binaural FM fittings produced significantly better SRTs than no FM condition, no significant difference was found between the two FM conditions. More recently, Umat *et al.*¹³ studied the benefit of monaural and binaural ear-level FM fittings on auditory working memory in 8 and 9 years old children with suspected auditory processing disorder. These children were selected based on their poor academic performance. They were assessed at pre FM fitting, after 12 weeks of FM usage and after one year of not using the FM system. It was found that there was no significant difference between the monaural and binaural groups in terms of their auditory memory performance.

Generally, the advantage of binaural over monaural FM receivers has been shown on subjects with hearing impairment, where FM receivers were fitted to their hearing aids.¹⁴ Generalization of this benefit on normally hearing children may not be accurate. Therefore, it is important to find out whether the same binaural advantage over monaural also applies to normal hearing subjects with FM system so that decisions on monaural versus binaural fitting can be supported by evidence. This is crucial since binaural FM systems not only costs more but also can be more challenging to care for. Furthermore, some children may prefer wearing one FM receiver rather than two. A study by Tharpe *et al.*¹² revealed that all 14 children in their study indicated their preference to wear only monaural FM receiver when asked of their preference. Although the study did not include reasons for monaural preference, it is possible that it could be due to comfort and/or cosmetic reasons.

The present study compared the benefits of monaural versus binaural ear-level FM fitting on speech perception in noise among typically developing normal-hearing school-age children. Speech reception thresholds for sentences in noise were measured using Hearing in Noise Test with and without the FM system, in monaural and binaural settings.

Materials and Methods

Subjects

Twenty-two subjects aged between 8 to 9 years were recruited on voluntary basis among school children around Kuala Lumpur. This age range was chosen because children ages 8 and 9 years old still require greater SNR when listening in noisy environment compared to adults.¹⁵ All subjects were native Malay speakers, had bilateral symmetrical normal hearing, and had no learning disability or any disabilities affecting speech production. All subjects underwent audiometric using Grason Stadler 61 audiometer connected to TDH-50 headphones and immittance tests using GSI TymStar to ensure symmetrical, normal hearing and middle ear function. Subjects' hearing levels were tested at octave frequencies between 250 to 4000 Hz bilaterally. In this study, symmetrical hearing was defined as inter-aural hearing threshold level difference of not more than 10 dB at any test frequency. Normal hearing was defined as hearing thresholds of not greater than 20 dBHL at any test frequency.

This study was approved by the Universiti Kebangsaan Malaysia Research Ethic Board. Informed consent was obtained from participants' parent prior to recruitment as study subjects. The procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975.

Test set-up

All tests were carried out in a treated sound booth with an average ambient noise level of less than 30 dB A. The subjects were seated one meter away at the X position (Figure 1) facing the single coned front loudspeaker (0° azimuth) throughout the test session. Speech signals were always presented from the front loudspeaker (0° azimuth), whereas babble noise was delivered through three other loud speakers positioned at 90°, 180° and 270° azimuths. The height of the loudspeakers was adjusted to approximate the ear-level position of the child when being seated. All the four loudspeakers were approximately 1 meter from the position of the subject.

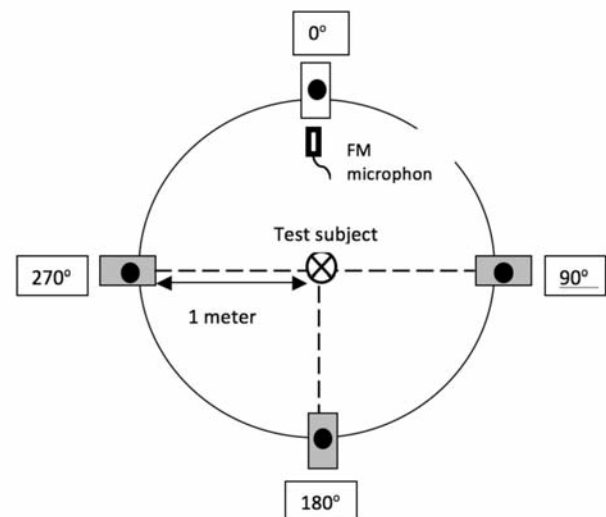


Figure 1. Sound field setup for speech perception in noise testing. The test subject was positioned 1 meter away from the 0°, 90°, 180° and 270° azimuths speakers.

frequency modulated system

Two Phonak Edulink ear-level FM receivers and Campus S FM transmitter with omnidirectional lapel microphone were used. Prior to the beginning of this study and on each test day, electroacoustic measurement of the system was conducted to verify that the output level was in accordance to the manufacturer specification. The volume control of the FM receiver was set at three-quarter level, which was consistent with comfortable level in all participants.

Speech perception

During this test, a prerecorded 4-talker babble noise was presented through a compact disc player that was routed to three loudspeakers positioned at 90°, 180° and 270° azimuths through an amplifier. The level of noise babble was adjusted through a volume control of the amplifier so that the three loudspeakers driven simultaneously produced a noise level of 65 dB SPL at the position of the test subject. The calibration of the four-talker babble noise was based on the 1000 Hz calibration tone which was recorded preceding the noise using a Quest 2700 sound level meter equipped with band pass filters. When the subject wore the Edulink FM system, the lapel omnidirectional microphone of the Campus S transmitter was positioned at approximately 20 cm in front of the diaphragm of the front (0° azimuth) loudspeaker. This setup was to simulate the position of the microphone when worn by schoolteachers in the classroom, which was approximately 15-20 cm from the mouth and facing the sound source.¹⁶ Figure 1 shows the sound field setup used in this study. In the unaided test condition, the FM transmitter was switched off and subjects did not wear the Edulink receiver.

Test procedure

Speech perception in noise was measured using the software-based Pediatric Malay Hearing in Noise Test (P-MyHINT)¹⁷ delivered via the loudspeakers. The procedure used in developing this test was similar to that reported by Nilsson *et al.*¹⁸ As in the original HINT,¹⁵ the P-MyHINT uses an adaptive test technique in which results are reported based on the reception thresholds for sentences (RTS). The RTS is defined as the signal-to-noise ratio in which 50% of the speech sentences were correctly repeated. The competing babble noise was kept constant at 65 dB SPL at the ear level of the test subject. The presentation level of the sentence stimuli was varied based on whether the previous sentence was repeated correctly or not. The standard HINT staircase adaptive procedure was used: for the first four sentences, a 4-dB step size was used to increase/decrease the signal presentation level, while for the remaining six sentences, a step size of 2 dB was used. The RTS in SPL was calculated based on the average presentation levels of sentences 5 through 11. On average the estimation of the RTS through the adaptive procedure took about 10 minutes per test condition.

The speech-recognition testing was conducted in no-FM, monaural FM, and binaural FM fitting conditions. Each subject had speech-recognition thresholds measured twice in each test condition. To minimize score bias due to learning effect, the test sequence was counter-balanced across subjects. For the monaural fitting condition, eleven of the subjects were fitted in the right ear while the rest were fitted in the left ear. Selection of subjects to be fitted either in the left- or in the right-ear was at random. To avoid lack of attention due to fatigue that might affect the speech-recognition threshold measurements, subjects were given approximately 10 minutes rest periods in between each sequence. Prior to testing, all subjects had a trial list to familiarize them with the test procedure and setup.

Results

Subjects

A total of 22 children aged between 8 to 9 years 11 months participated in this study. Their mean pure-tone hearing thresholds at three frequencies (i.e. 0.5, 1 and 2 kHz) for the right and left ears were 10.30±2.89 dB HL and 10.61±3.02 dB HL, respectively. Paired t-test showed no significant difference between the mean thresholds of the two ears ($P>0.05$). All subjects had normal middle ear function as measured using immittance testing.

Data analysis

Data screening using the Shapiro-Wilk test indicated that all data for speech perception in noise were normally distributed. Therefore, parametric tests were used in the analyses. The means RTSs obtained in the first and second testing were compared using a paired t-test to assess the test-retest reliability of these measurements. For each test condition, no significant differences were found between the RTSs obtained during the first and second measurements, ($P>0.05$), with the test-retest reliability of intraclass correlation coefficients (ICC) = +.59, CI95% (.03, .82) for RTS without FM system, ICC = +.42, CI95% (-.38, -.76) for RTS with monaural FM system and ICC = +.39, CI95% (-.44, .75). Therefore, the average values of RTSs in each test condition were used in the final analyses. One-way repeated measures ANOVA was used to calculate within subject comparisons of RTS values obtained in different FM fitting conditions; that is, in no-FM, monaural and binaural FM usage. An alpha level of 0.05 was used in all statistical tests.

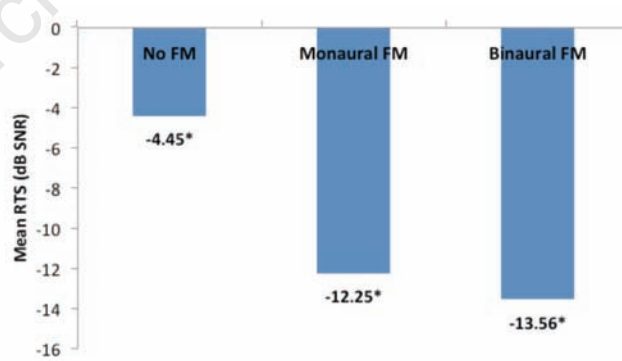


Figure 2. Mean RTSs for no-FM, monaural FM and binaural conditions. *Significant differences were observed between RTS in no-FM and other FM conditions ($P<0.001$).

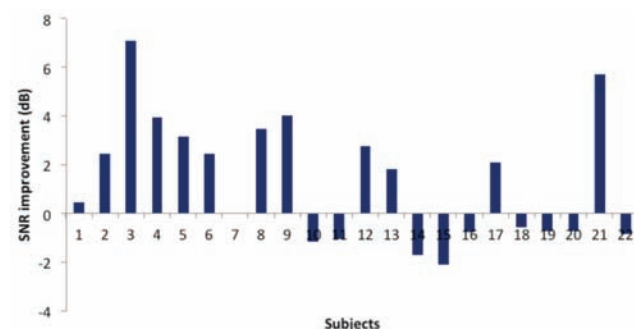


Figure 3. RTS differences between binaural and monaural FM conditions for each subjects. Positive values indicate better RTS, whereas negative values indicate poorer RTS.

Reception threshold for sentences

Figure 2 shows the mean reception threshold for sentences (RTSs) obtained in no-FM, monaural FM, and binaural FM conditions. Both FM fitting conditions produced better RTS values (that is lower SNRs) than the no-FM condition. The mean RTS for the no-FM condition was -4.45 ± 2.46 dB SNR; Confidence interval, CI95% $(-5.54, -3.36)$, whereas the means RTS for the monaural FM and binaural FM conditions were -12.25 ± 1.65 dB SNR; CI95% $(-12.98, -11.52)$ and -13.56 ± 1.92 dB SNR; CI95% $(-14.41, -12.71)$, respectively. Monaural and binaural FM fitting conditions consistently produced better RTSs than no-FM condition in all subjects. A one-way repeated measures ANOVA showed a significant effect of FM-fitting condition [$F(2,42)=121.64$; $P<0.001$; effect size = 0.853, power = 100%]. Pair wise comparisons with Bonferroni correction showed that the no-FM condition yielded a significantly poorer RTS than monaural and binaural FM-fitting conditions, ($P<0.001$). However, binaural fitting condition did not produce a significantly better RTS than monaural condition, $P=0.073$.

Individual subject's data for monaural and binaural FM fitting

Although generally, binaural FM-fitting is expected to produce better RTS than monaural fitting, the present study revealed that this was not always the case for normal-hearing children. Figure 3 summarizes the dB SNR improvement from binaural over monaural FM fitting. Subjects 1 through 11 had the monaural fit on the right ear, whereas in subjects 12 through 22, the monaural fit was on the left. Only 12 subjects (54.55%) had SNR improvement in binaural fitting condition, one subject (4.54%) had equal RTS values in monaural and binaural fitting conditions (no improvement), whereas the remaining 9 subjects (40.91%) showed deterioration of performance in binaural condition.

Discussion

The present study examined the benefits of using monaural and binaural ear level FM receivers on speech perception in normally hearing children. The results revealed that while the use of FM system use provided significant benefits over the no-FM condition, the use of binaural FM receivers did not produce a significantly greater benefit over monaural FM fitting on speech perception in noise. Thus, our hypothesis that binaural FM fitting would provide significantly higher benefits than monaural FM fitting was not supported in this study.

In the present study, the difference of RTSs between monaural and binaural FM fitting was 1.3 dB and did not reach significant level. This small difference between binaural and monaural FM fitting could be due to the fact that the subjects in the present study had binaural normal hearing and their unaided ear was not occluded during monaural FM condition. Therefore, even in the monaural FM condition, they could still experience binaural hearing because the unaided ear received direct signal, albeit at lower SNR levels. The overall results of the present study were similar to the Tharpe *et al.*¹² study. In that study, researchers investigated the benefit of ear level FM systems on speech perception in 14 children comprising of those with bilateral minimal to mild hearing loss, unilateral hearing loss and high frequency losses, aged between 5 to 11 years old. Speech recognition threshold at different azimuths using the Hearing in Noise Test for Children was measured in 4 conditions; i) unaided, ii) monaural FM with open mold, iii) monaural FM with skeleton mold and, iv) binaural FM with open molds. Repeated measures ANOVA revealed a significant main effect of listening condition, in which the unaided condition yielded a significantly poorer RTS than any of the aided conditions. However, comparison of RTSs between FM conditions did not yield any significant differences in performance between different FM configurations.

In the present study, the individual subjects' data indicate variability

in the SNR improvement or deterioration received from binaural over monaural FM fitting. In one subject, binaural FM fitting improved RTS by as much as 7.10 dB SNR, whereas another subject demonstrated RTS deterioration by 2.10 dB SNR. The wide range between the best and the poorest SNR improvement suggests that although slightly over 50% of subjects performed best with binaural FM fitting, there were those in whom binaural FM fitting produced either deterioration of SNR than or no additional improvement compared to monaural FM fitting. Therefore, expressing the binaural over monaural FM benefit in terms of the group mean SNR improvement masks the fact that some children have poorer speech perception in noise with binaural compared to with monaural FM fitting. Better RTS obtained in monaural than binaural FM fitting seen in some of the children in the present study might be due to binaural interference. The auditory system, specifically the corpus callosum, which is considered to play an important role in interhemispheric transfer of information,¹⁹ is still developing in preadolescence children and it only attains maturation in the mid twenties.²⁰ Because the right ear has a dominant access to the left hemisphere, the hemisphere dominant for processing language, dichotic listening results in a better score in the right than the left ear, a phenomenon known as right ear advantage.²¹ Therefore, poorer performance in binaural FM condition found in some of the children in the present study may be due to the left auditory input being suppressed by the right auditory input in binaural listening.²² This phenomenon could interfere with binaural processing, which may partially, explain the deterioration of performance in binaural FM condition seen in some of the children in the present study.

The findings indicated that RTS differences were not statistically significant between the two FM configurations. In other words, while binaural FM fitting configurations improved RTS in about 50% of the study subjects, generally, the benefit of binaural FM receivers on speech perception in noise was not significantly better than monaural fitting. These data suggest that some of the children at risk for listening deficits in the classroom could benefit as much from monaural as from binaural FM fitting. This latter finding highlights the importance of making a decision on whether to fit a child with monaural or binaural FM based on individual subject's measurement rather than assuming that binaural fitting will benefit every child. For example, functional evaluation of monaural versus binaural FM fitting can be compared in a listening environment which simulate that the child will encounter to ascertain the best FM configuration.

Although these results were obtained from normally functioning normal hearing children, they provide information regarding the SNR benefit of monaural and binaural FM fitting that might be applicable to populations of normally hearing children who are at risk for having difficulty understanding speech in less conducive acoustic environments such as the classroom setting. These populations include children with auditory processing disorder, learning disability, language delay or disorder, and attention deficit disorder. Research has demonstrated potential FM benefit in these populations.^{4,23,24}

It should be mentioned, however, while the present study attempted to re-create the challenges faced for children listening in a noisy classroom, the laboratory setting can never exactly replicate the *real world*. Further, the subjects in this study were normal hearing children with no learning disability or other conditions that put them at risk for listening difficulties in the classroom. The study by Johnston *et al.*⁴ for example, showed that children with APD obtained a significantly greater SNR benefit from the use of ear-level FM receivers than the normally developing normal hearing control group. It is possible that the change in performance from monaural to binaural might be different in APD and non-APD. Thus, one should use caution in generalizing the present results to normal hearing children with learning or other auditory related disabilities. It is possible that children with conditions that put them at greater risk to hearing difficulty in noise, such as

learning disability and auditory processing disorder may attain a significantly greater benefit from binaural fitting than from monaural.

It is difficult to predict whether children younger or older than those participated in the present study would benefit differently from FM system. It is well known that in children, the magnitude of right ear advantage reduces with the increasing age.^{21,25} Based on this premise, older children are less likely to experience binaural interference and thus may benefit more from binaural FM fitting than children in the present study. However, a study by Kreisman and Crandell¹¹ who compared the benefit of body worn FM system, monaural ear-level FM system and binaural ear-level FM system on 20 normally hearing adults indicated that none of the FM system configurations improved speech recognition more than another. This suggests that there could be other factors than binaural interference, which influence the magnitude of benefit from binaural FM fitting.

Conclusions

The present study revealed that the use of an ear-level FM system significantly improved speech perception in noise compared to listening without an FM system. Although group data did not show a significant difference in performance between monaural and binaural fitting, individual data indicate variable benefit of binaural over monaural FM fitting, which suggests that the decision to employ monaural or binaural fitting should be individualized. The finding of similar improvement on speech perception in noise from either monaural or binaural FM fittings is clinically important because it indicates that monaural FM fitting could be indicated when fitting normally hearing children. The advantages of monaural FM fitting are three fold: i) it lowers the cost borne by parents or school districts for purchasing the FM system, ii) one FM receiver is easier to care for than two FM receivers, and iii) wearing a monaural FM receiver may be more comfortable than wearing two for some children. It should be emphasized, however, that the present data were obtained from normally developing normal hearing children. A similar study involving children with special listening needs such as reading delays and auditory processing disorder should be carried out to determine if similar findings apply to these groups of children.

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