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Speech Perception through FM Auditory Trainers in Noise and Reverberation[a]

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Abstract — Speech perception through FM auditory trainers was explored in conditions of noise and reverberation. Special attention was paid to the mode of transmission and individual capabilities of various commercially-available units to handle speech in noise and reverberation. Results indicate an overwhelming advantage of FM transmission for maintaining speech intelligibility in noise and reverberation, irrespective of the instrument.

INTRODUCTION

Hearing aids have been designed primarily to amplify sounds. In so doing, they amplify virtually all of the sounds picked up by the microphone, irrespective of their relevance to the listener. Because of this lack of selectivity, hearing aids have been shown to be of little or no benefit to their users for speech perception in conditions of noise and reverberation: see Plomp, 1978 (1) and Nabelek, 1980 (2). This is especially true of hearing aid users with sensorineural hearing loss. Degradation of auditory capabilities of sensorineural listeners and, more particularly, the loss of frequency selectivity in such cases, have been evoked as reasons for increased difficulties in understanding speech under adverse listening conditions: see Evans, 1978 (3); Scharf, 1978 a,b (4) and Plomp, 1978 (1).

Two principal solutions have been employed to help circumvent the adverse effects of noise and reverberation on the intelligibility of amplified speech.

The first alternative relies on the introduction of small directional microphones as transducers for hearing aids as described by Hillman in 1981 (5). Because of their ability to attenuate sounds arriving from the back and the side, directional microphones had been expected to cancel out part of the noise and echoes otherwise amplified by a hearing aid equipped with an omnidirectional microphone: see Mueller, 1981 (6).

Over the years, however, hearing aids containing a directional microphone have been found not to show the expected advantages when worn on the head (5). A possible reason is that the microphone did not succeed in making use of or simulating the natural directional properties of the external ear, as suggested by Franks, 1979 (7). A more serious limitation is that directional microphones are of limited benefit in a reverberant environment, as demonstrated by Studebaker et al. in 1980 (8). Under reverberant conditions, reflected components of both the signal and noise are picked up by the microphone, despite its directional characteristics.

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The second solution involves the placement of a microphone close to the speaker's mouth in order to reduce the sound pressure level of the reverberant field relative to that of the source. Although this approach has been reputed to be an impractical one in daily use, according to Plomp writing in 1978 (1) and Shaw in 1980 (9), it has known widespread application in the classroom in connection with the use of FM auditory trainers, as described by Matkin and Olsen in 1973 (10); by Hambleton in 1976 (11), and by Freeman and Sinclair in 1979 (12). FM auditory trainers consist of a standard body hearing aid equipped with an FM receiver as an auxilliary input channel. This channel is used to pick up the voice of a talker, at a remote location, who is using a portable FM transmitter-microphone.

To date, few studies have quantified the beneficial effects of FM auditory trainers on speech perceived in noise and reverberation. Ross and Giolas in 1971 described one such benefit in a classroom situation when a distance of 12 feet separated a speaker from young hearing impaired listeners (13). Carson in 1976 found improved discrimination scores when an FM auditory trainer was substituted for conventional hearing aids in two different academic settings (14). However, the two studies (13, 14) lack generality in that they failed to study the influence of noise and reverberation on the performance of the FM systems: see Nábělek, 1980 (2). These studies also did not include representative samples of auditory trainers currently available. Comparisons among FM systems have been made but only with respect to electroacoustic characteristics: see Griffing and Hayes, 1968 (15); Van Tasell and Landin, 1980 (16); and Freeman et al., 1980 (17). That information is helpful but there is a need for an overall evaluation in which both electroacoustic and psychoacoustic effects are taken into account and, specifically, to check whether differences found in acoustical fidelity do, in fact, influence speech perception in degraded listening environments.

Focus of the Present Study: Two Experiments

The present study is concerned with the above issues. It is part of a larger research project dealing with the efficiency of FM auditory trainers as rehabilitative tools in audiology. Two experiments are reported which are attempts to answer the following questions:

1. Do FM auditory trainers used in the FM mode improve speech intelligibility in conditions of noise and reverberation as compared to the mode of operation in which a conventional head- or body-worn microphone is used?

2. Are there any differences in the capability of the various commercially-available FM auditory trainers to handle speech in noise and reverberation?

EXPERIMENT I
(Mode of operation of FM auditory trainers and the effect on speech perception in degraded listening environments.)

A first experiment was conducted to study the intelligibility of speech recorded through an FM auditory trainer in both its conventional and FM modes of operation. Recordings were obtained in two different reverberant enclosures, 96-m^3 and 240-m^3 regular classrooms (3400 and 8500 cubic feet) using two types of competing signals (classroom noise and speech babble).

Subjects

Eight young adults with no history of ear pathology participated in Experiment I. They all evidenced hearing thresholds within 10 dB at .5, 1 and 2 KHz in the tested ear: see ANSI, 1969 (18).

Recording

The speech material consisted of four lists of a closed set discrimination test prepared by Hébert and Picard and published in 1979 (19). The twenty-item lists were recorded by a French-Canadian female speaker, through a Telex FM auditory trainer, model TDR-5, provided with a TW-3 transmitter-microphone. The electroacoustic characteristics of this system are shown in Table 1. The table shows the measured performance of the instrument on a 2-cc coupler as it was adjusted in its FM and conventional modes of operation. In order to increase the differences between the two experimental conditions, the highest setting of maximum power output was used in the 3400-cubic-foot room (SSPL − 90 = 139 dB) and the lowest setting of power output (SSPL − 90 = 118-to-122 dB) was used in the 8500-cubic-foot room. These settings were chosen in an attempt to increase the contrast in speech intelligibility between the experimental conditions.

Recordings were made through the auditory trainer and a Zwislocki coupler mounted on a KEMAR manikin: see Burkhard, 1978 (20). The manikin was placed in 3400-cubic-foot and 8500-cubic-foot classrooms as illustrated in Figure 1. In the FM mode, the transmitter-microphone was located 15 feet away from the manikin, at the point where the two speakers delivering speech converged. A second set of loudspeakers was located on the side of the manikin at a distance of three feet. They were

TABLE 1
Electroacoustic performances of the auditory trainer used in Experiment I in 3400-cubic-foot and 8500 cubic foot classrooms, in conventional and FM modes of operation.

	3400 cubic feet		8500 cubic feet	
	Conv.	FM	Conv.	FM
Aver. HF-gain (dB)[1]	78.3	76.6	64	64.5
Max. HF-gain (dB)[2]	84	86	71.5	67.5
	(2 kHz)	(1.8 kHz)	(.2 kHz)	(1.8 kHz)
Bandwith (KHz)[3]	.2-3.8	.25-3.6	.2-3.8	.35-3.2
SSPL-90 (Lp)[4]	139 (.2 & 2 kHz)	139 (1.8 kHz)	122 (.2 kHz)	118 (.25 kHz)
THD (%)[5] .5 KHz	13	32	2.4	4.6
.8 KHz	13	45	2.9	6
1.6 KHz	3.75	7	1.4	1
EIN (dB)[6]	11.7	19.4	19.3	21.1

[1]As per ANSI, 1976 (26), measured with a 50 dB input at full-on volume.
[2]Measured with a 50 dB input at full-on volume.
[3]Measured 10 dB below Aver. HF-gain.
[4]Saturation SPL as per ANSI, 1976 (26), measured at full-on volume.
[5]Total Harmonic Distortion as per ANSI, 1976 (26), measured at full-on volume.
[6]Equivalent Input Noise as per ANSI, 1976 (26), measured at full-on volume.

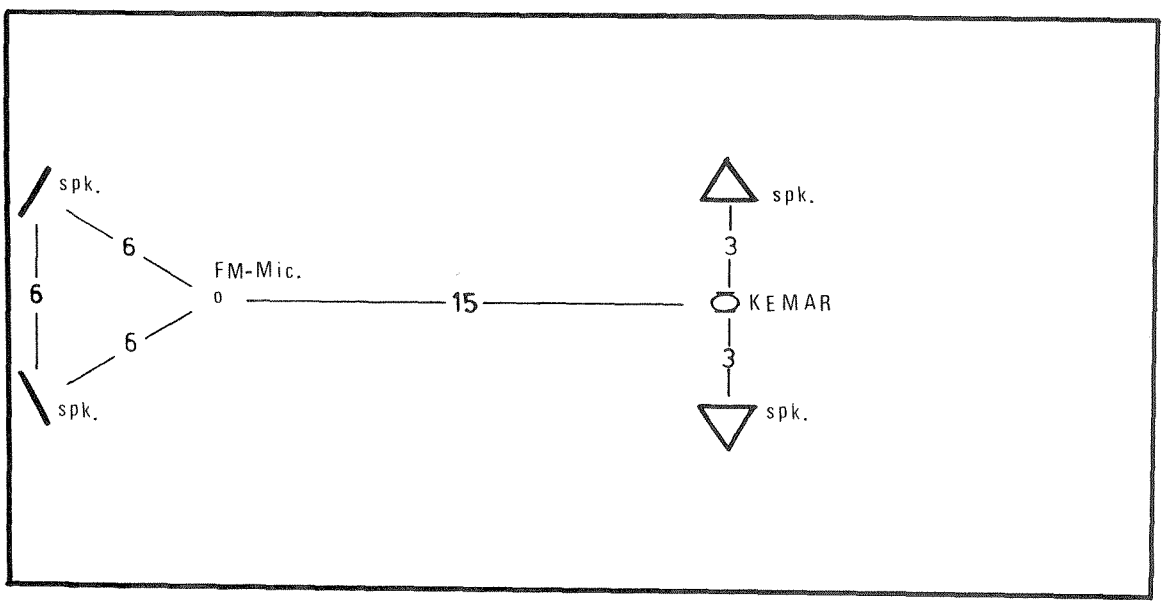

FIGURE 1
Physical arrangement for recording through an FM auditory trainer (distances in feet).

used to mix speech babble with the primary speech signal. The competing signal was adjusted so as to produce a sound pressure level of 76 dB (Lp) in the Zwislocki coupler. Ambient classroom noise was used as a second interfering signal. The sound pressure level of this noise was 55 dB (Lp) in the Zwislocki coupler.

The primary speech signal produced a sound pressure level of 84 dB as measured 15 feet from the manikin. The loudspeakers were located 6 feet from the microphone so as to avoid proximity effects: see ANSI, 1971 (21). The target level of 84 dB (Lp) was chosen in accordance with current data on speech acoustics (15, 22, 23, 24) to approximate the

average sound pressure of conversational speech measured 6 inches away from the lips of the talker.

Reverberation times (RTs) of 0.34 and 0.51 seconds were measured at the location of the manikin in the 3400- and 8500-cubic-foot rooms, respectively. Values recorded were averaged over .5, 1, and 2 KHz as recommended by Carson in 1976 (14) and Kuhn in 1980 (25).

The measured reverberation times at the point of convergence of the loudspeakers were 0.33 seconds and 0.44 seconds, in the smaller and the larger classrooms, respectively. These durations implied that primary speech was mixed with late reflections (that is, reverberation) in all four conditions. Indeed, late reflections occur 50 msec after the cessation of the signal, according to Berkley, 1980 (26).

Presenting the stimuli

Recordings obtained under the experimental conditions described above were presented in randomly selected order to each subject. The subject sat in a sound-treated room and listened to the stimuli presented monaurally through an earphone at an average sound pressure level of 80 dB. A closed-response-set format was used in which the subject was required to cross out the word that was heard, or the closest approximation to that word. The response set consisted of six alternatives, one of which was the CVC target word. Four of the error responses differed minimally from the target word on a single phoneme; e.g., pain, bain, main, nain.

Results

The data were analyzed using a three-factor analysis of variance. The SP 2(2,2) design of Kirk, 1968 (27) was chosen because of its simultaneous analysis of independent and related observations. Table 2 summarizes the findings; it reveals a significant three-factor interaction of rooms (covarying with hearing aid SSPL setting) and modes of operation of FM trainers and competing signals ($p \leqslant .01$).

Figure 2 illustrates how the mode of operation of FM auditory trainers affected speech discrimination in various conditions of background noise and reverberation time. Speech discrimination scores were significantly higher for three of the four conditions using the FM mode of operation. (Significance level $\leqslant .01$ according to the Tukey HSD test (1953) in Kirk, 1968 (27). The one exception to this trend was that of the smaller classroom, with low-level background noise. The improvement obtained in the large classroom with (relatively) low-level background noise was 19 percentage points. Larger improvements were obtained when the competing signal consisted of relatively high-level speech babble; the improvements were 50 and 24 percentage points for the smaller and the larger rooms, respectively.

TABLE 2
Analysis of variance table for room volumes (V), background noise (N) and mode of operation of auditory trainers (O).

source	SS	dF	MS	F
Between	10353.44	15		
V	8418.06	1	8418.06	60.89**
error 1	1935.37	14	138.24	
N	19740.25	1	19740.25	184.58**
VxN	5329.00	1	5329.00	49.83**
error 2	1497.25	14	106.94	
O	7965.56	1	7965.56	56.81**
VxO	18.06	1	18.06	—
error 3	1962.87	14	140.20	
NxO	3364.00	1	3364.00	49.20**
VxNxO	2070.25	1	2070.25	30.28**
error 4	957.14	14	68.37	
Total	53257.8	63		

**$p \leqslant 0.01$

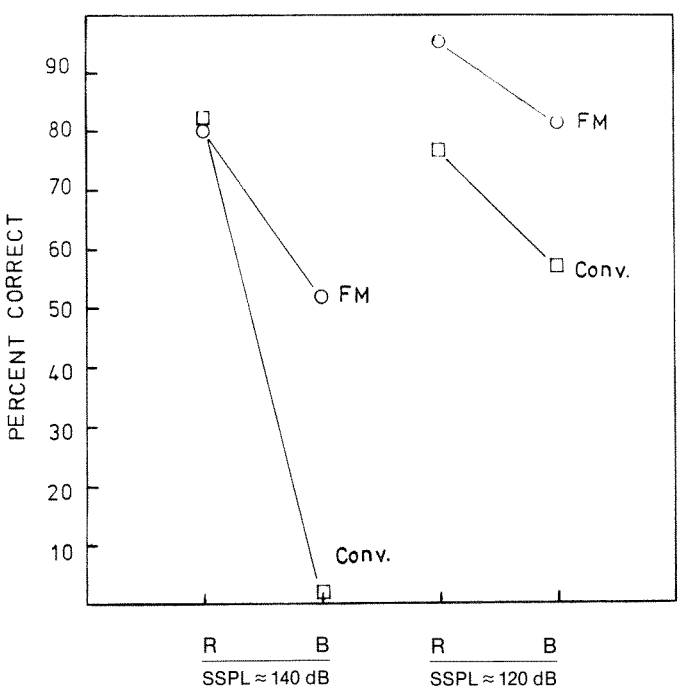

FIGURE 2
Mean discrimination scores of amplified speech as a function of ambient noise, size of the test enclosure and mode of operation of the Fm trainers (R = classroom noise = 55 dB (lp); B = speech babble = 76 dB (Lp). Primary speech signal reference level = 84 dB (Lp).

EXPERIMENT II

(Speech perception through different FM auditory trainers.)

A second experiment was carried out with four different commercially available auditory trainer units. The intent was to reveal possible differences in the way present systems could maintain speech intelligibility in noise and reverberation. The method used recordings of speech obtained with auditory trainers mounted on a KEMAR mannikin in a manner similar to that described in Experiment I.

Subjects

Forty young adults with no history of ear pathology participated in the experiment. They all evidenced hearing sensitivity within 10 dB as described in ANSI, 1969 (18), over frequencies of 500 Hz, 1000 Hz, and 2000 Hz in the tested ear. People were randomly assigned to one of four experimental groups (n = 10).

Recording and Presenting the Stimuli

Six recordings were prepared to explore the selective effects of four FM auditory trainers on speech perception: for each system, speech discrimination lists were recorded over three backgrounds of noise, in both the FM and conventional modes of operation. Competing signals consisted of: first, a classroom noise (Lp = 55 dB), second, speech babble at a sound pressure level of 76 dB (Lp), and third, cafeteria noise at 74 dB (Lp). All sound pressure levels were measured in a Zwislocki coupler. Cafeteria noise was included because of the abundance of impulsive sounds which typically characterize this type of signal and the likelihood of its producing "blocking distortion" as described by Killion in 1980 (28), or amplifier overload.

Recordings were made in the 8500-cubic-foot classroom using procedures identical to those used in Experiment I. The four auditory trainers tested consisted of two Phonic Ear systems (models 431 and 445), one Telex (model TDR-5), and one Biocoustic unit (model B-77). The equipment was tested with its accompanying transmitter-microphone. Table 3 illustrates the electroacoustic characteristics of all these instruments as they were adjusted at the time of the experiment in their conventional and FM modes of operation. For reasons

TABLE 3
Electroacoustic performances of the auditory trainers used in Experiment II, in conventional and FM modes of operation.

	PE431		PE445		B-77		TDR-5	
	Conv.	FM	Conv.	FM	Conv.	FM	Conv.	FM
Aver. HF gain (dB)[1]	41.5	40	43.5	66	57	60.8	64	64.5
Max. HF gain (dB)[2]	44 at 2.8 Khz	42 at .5 & 2 Khz	46 at .2 Khz	69 at 2 kHz	60 at .5 kHz	63 at .5 kHz	71.5 at .2 kHz	67.5 at 1.8 kHz
Bandwidth (KHz)[3]	.2 5.6	.2 4.6	.2 4.1	.25 3.9	.2 4.7	.2 5.5	.2 3.8	.35 3.2
Max. SSPL-90 (Lp)[4]	114.2 at 2 kHz	120 at 2 kHz	133 at 2 kHz	134.5 at 2 kHz	135 at .5 kHz	135 at .5 kHz	122 at .2 kHz	118.2 at .25 kHz
THD (%)[5] .5 kHz	2.25	2.5	20	27	13	7.5	2.4	4.6
.8 kHz	1.75	2.6	13.5	20	15	9.4	2.9	6
1.6 kHz	1.4	1.75	3	5	6.25	4.3	1.4	1
EIN (dB)[6]	17.4	15.7	17	22.4	20	19	19.3	21.1

[1]As per ANSI (1976); measured with a 50 dB input at full-on volume.
[2]Measured with a 50 dB input at full-on volume.
[3]Measured 10 dB below Aver. HF-gain.
[4]Maximum value of saturation SPL; measured as per ANSI (1976) at full-on volume.
[5]Total Harmonic Distortion as per ANSI (1976); measured at full-on volume.
[6]Equivalent Input Noise as per ANSI (1976); measured at full-on volume.

of convenience, measurements were obtained on a 2-cc coupler. However, recordings were made through the Zwislocki coupler mounted on KEMAR.

The procedure for the listening test was the same as in the previous experiment.

Results

A three-factor analysis of variance was applied to the data. The SP 4(2,3) design of Kirk, 1968 (27), was chosen for the same reasons noted in connection with Experiment I.

Table 4 summarizes the results. It indicates the presence of a significant three-factor interaction ($p \leqslant .01$): intelligibility of speech changed from one FM system to another depending upon the mode of operation and the competing signal introduced.

Figure 3 illustrates how experimental effects mutually influenced each other. The critical value corresponding to a significant difference between a pair of means was calculated using the Tukey HSD of 1953 in Kirk (27). The departure of 13 percent thus obtained for a confidence level of 0.01 confirmed the presence of a systematic difference between the Phonic Ear model 431 and model 445 FM trainers in cafeteria noise, when each unit was set in the FM mode. The model 445 instrument showed more deleterious effects on speech perception than the former. All other equipment produced uniformly high discrimination scores irrespective of the acoustic environment while operating in the FM mode.

TABLE 4
Analysis of variance table for brand of auditory trainers (B), their mode of operation (O) and background noise (N).

source	SS	dF	MS	F
Between	281.93	39		
B	63.30	3	21.11	3.47
error 1	218.63	36	6.07	
O	1179.26	1	1179.26	224.90**
BxO	81.63	3	27.21	5.19
error 2	188.76	36	5.24	
N	781.36	2	390.68	145.25**
BxN	313.97	6	52.33	19.45**
error 3	193.66	72	2.69	
OxN	411.80	2	205.90	53.22**
BxOxN	391.99	6	65.33	16.88**
error 4	278.53	72	3.87	
Total	4102.8	239		

**$p \leqslant 0.01$

When auditory trainers were used in their conventional mode of operation, more differences were shown. First, with cafeteria noise as a background, the Phonic Ear model 445 produced significantly better discrimination scores than either the Telex or the Phonic Ear 431 system. These two models, in turn, maintained intelligibility at a significantly higher level than the Biocoustic B-77.

Under the condition of primary speech material imbedded in babble, the Telex TDR-5 showed a significantly lower intelligibility score than either the Biocoustic B-77 or the Phonic Ear 431. However, the difference between the TDR-5 and the PE 445 scores was not great enough to reach statistical significance, nor did the PE 445 unit's performance differ from either that of the B-77 or the PE 431 under the condition.

With classroom noise, effects upon intelligibility scores were present between only two auditory trainers: speech was significantly more intelligible when processed through the Biocoustic unit as compared with the Telex TDR-5. (Differences in test scores between the other instruments were not statistically significant.)

DISCUSSION

Experiment I was carried out to determine whether or not FM auditory trainers improve perception of remote speech while used in FM mode; that is, with their portable FM transmitter-microphone positioned close to the lips of a person talking at a distant location. Results indicate a clear ability of the devices to maintain speech intelligibility in various listening environments when distant messages are received uniquely through the transmitter-microphone. Improvements in discrimination scores from 19 percent to 50 percent were found in the less favourable listening environments. These findings unanimously support previous information indicating that FM trainers used in the FM mode do succeed in isolating speech from unwanted noise and echoes in situations where someone is speaking from a remote location in a non-acoustically-treated environment.

When listening conditions were more favourable (as when speech was introduced over a classroom noise level of 55 dB (Lp), S/N≥24 dB, in a small non-acoustically-treated enclosure) performances of the FM auditory trainers were found to be identical in tests in both their conventional and FM modes of operation. Scores of 80 percent were typical. The reason for such a consistently high performance irrespective of microphone location

can be attributed to the quality of the listening environment. Indeed, SNins* rated high in this experimental condition. Also, reverberation times for these conditions were found to be relatively small, ranging from .33 to .45 seconds. That is to say, the acoustic environment thus created was almost "ideal" for hearing-aid users, in accordance with Nábělek (2) who suggested a maximum reverberation time of .5 sec. in a medium-size (120 m^3 to 160 m^3) enclosure intended for hearing impaired listeners. She also recommended that such rooms have ambient noise levels allowing for speech-to-noise ratios in excess of 15 to 20 dB.

In summary, one can conclude from the present findings that in highly favourable listening conditions such as the one created by low ambient noise level (Lp ≈ 55 dB) in a small, almost non-reverberant enclosure (≈ 100 m^3), the use of FM auditory trainers in the FM mode does not facilitate perception of remote speech. However, in more reverberant and/or noisy rooms, such as are currently found in daily life, there is overwhelming evidence in favor of trainers used in the FM mode for optimum speech reception from a remote location. Indeed, FM transmission proved to be the only solution, among those envisaged, which seemed likely to so dramatically facilitate perception of remote speech in such universal conditions.

For these reasons, the use of FM auditory trainers in the FM mode certainly does appear to be a forceful rehabilitative tool. This is especially true of situations where faint or remote speech has to be perceived by hearing-impaired listeners in non-acoustically treated enclosures — including, but not limited to, the classroom situation.

Practical application of the system, however, deserves careful attention. Advantages are evident in situations where the transmitter-microphone is used exclusively by a single speaker for long-distance (more than 10 feet) conversation — a parent at home, the teacher in the classroom, etc. In multi-talker situations, however, the device will totally lack convenience: the use of external directional microphones as an auxiliary input to conventional hearing aids might prove a more efficient solution.

In situations where young hearing impaired children are to be raised in noisy environments such as apartments located in densely populated areas

*SNins and SNouts refer to signal-to-noise (S/N) ratios as measured at the input of a device or system and at the output of a system. The same usage is applied to reverberation times (RTs) as in RTins, RTouts.

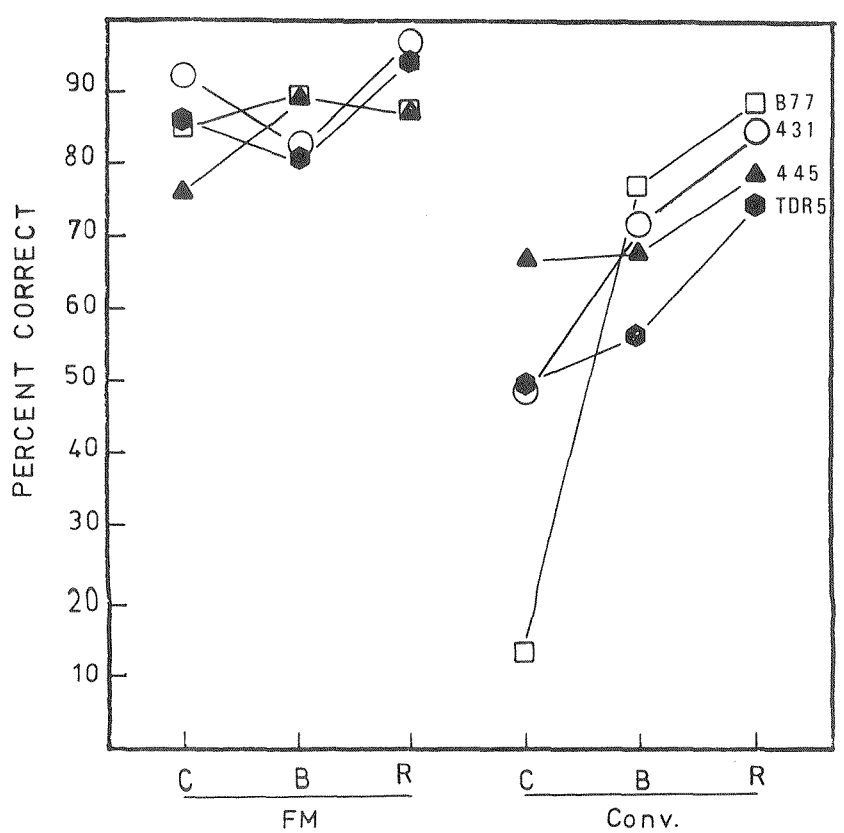

FIGURE 3
Mean discrimination scores of amplified speech as a function of ambient noise, brand of the auditory trainer and its mode of operation (C = cafeteria noise at 74 dB (Lp); B = speech babble at 76 dB (Lp); R = classroom noise at 55 dB (Lp). Primary speech signal reference level = 84 dB (Lp).

and places situated near sources of high-level community noise (highways, flight paths, etc.), FM auditory trainers should be given preference over conventional hearing aids for mid-distance (6 to 10 ft) or even short-distance (3 to 5 ft) conversation. Indeed, in conditions such as those mentioned above, present results indicate that amplifying devices used with their environmental microphones cannot cope with speech imbedded in noise as efficiently as can trainers used in the FM mode. This statement would also apply to conventional hearing aids equipped with so-called "directional microphones," as these systems were shown to become "functionally nondirectional in commonly encountered environments" by Studebaker et al. in 1980, p. 104 (8). In such conditions, conventional hearing aids, whether directional or not, would result in extensive exposure to truncated speech patterns.

The way various brands of FM auditory trainers amplified speech in noise and reverberation was explored in experiment II. As it can be seen from Figure 3, results indicate that three of the four units tested performed equally well in the FM mode. However, the PE 445 proved inferior: discrimination scores significantly lower than those associated with the PE 431 were obtained with the unit operating in cafeteria noise.

The explanation for this behaviour does not seem to be related to noise and reverberation. Indeed, SN and RT at the output of the Telex TDR-5 were even more adversely affected (i.e., lowered SNout and elongated RTout) than in the case of the PE 445. Electroacoustic characteristics of the PE 445 system, and especially total harmonic distortion (THD) seem to account more readily for the unit's behaviour in the FM mode. Indeed, while operating in this fashion, the PE 445 evidenced THD amounting to 27 percent and 20 percent at 500 Hz and 800 Hz, respectively, constituting the worst performance of all the systems tested. Conversely, the PE 431 produced figures of 2.5 percent and 2.6 percent, respectively, in similar conditions. These turn out to be the smallest THD percentages in all units compared.

Such a finding also applies to the Telex system of Experiment I: while adjusted without output limiting in the FM mode, this trainer generated 32 percent and 45 percent THD at 500 Hz and 800 Hz, respectively. Discrimination scores in noise (namely, speech babble) thus averaged 52.5 percent. Under similar experimental conditions but for a larger enclosure and maximum output limiting, results improved dramatically in spite of a reduced SNin and an elongated RT. Interestingly enough, discrimination scores in excess of 80 percent were thus associated with THD amounting to 4.6 percent and 6 percent at 500 Hz and 800 Hz respectively.

Thus, it appears that speech babble as a competing signal (as well as cafeteria noise) created a selective amplifier overload or "blocking" distortion of certain auditory trainers during their operation in the FM mode. The phenomenon would be attributable to the simultaneous presence in the amplifying device of high level amplification and THD. Repetitive high peak level transients typical in both competing signals would, therefore, saturate input stages of the amplifier, thus generating THD in amounts sufficient to affect speech intelligibility adversely.

When the FM auditory trainers of Experiment II were used in their conventional mode of operation (that is, with their environmental microphones) a widespread range of speech discrimination scores was noticed. For example, the B-77 unit evidenced greater efficiency than the Telex system in the quietest experimental condition. High gain characteristics in the absence of output limitation seems the logical explanation for the superior performance of the B-77 system. Indeed, the most dramatic difference observed between the two systems lay in their SN and RTouts which are directly influenced by gain and output limiting characteristics. In the case of the TDR-5, because the unit limited output to sound pressure levels of 122 dB as opposed to 135dB for the B-77, the contribution of background noise and its smearing was overemphasized, thus permitting more interference with speech.

In cafeteria noise, however, the B-77 FM trainer performed poorly and consequently, adversely affected speech discrimination. High level amplification associated with sizable amounts of THD (13 percent and 15 percent respectively, at 500 Hz and 800 Hz), might have generated "blocking" distortion similar to that thought to be created by the PE 445 instrument used in the FM mode. However, the PE 445 succeeded better in maintaining speech intelligibility in cafeteria noise. Moderate gain (HF gain = 43.5 dB) without output limiting apparently allowed for reasonable separation of speech and blurring echoes, as evidenced by the small RTout associated with the unit performing under that experimental condition. In addition, the electroacoustic attributes aforementioned apparently did not permit high level THD present in the device to interfere with speech perception (20 percent and 13.5 percent at 500 Hz and 800 Hz, respectively).

When FM trainers were used in a conventional manner with speech babble as a competing signal,

the TDR-5 unit had a more deleterious effect on perception than either the B-77 or the PE 431 system. High gain and low-level saturation output seem to be responsible for such an effect. Measurements of reverberation time at the output of the TDR-5 unit were found to be relatively large (1.44 seconds) and may have been an additional factor.

In summary, FM auditory trainers acted selectively on speech perception in various listening conditions, depending upon their electroacoustic characteristics and mode of operation. The FM mode of operation of these devices, however, made noteworthy contributions to the maintenance of high discrimination scores irrespective of brand and/or electroacoustic characteristics in most circumstances.

There are practical implications to such a finding. The use of FM speech transmission systems provides an opportunity for more flexibility of electroacoustic characteristics without compromising perception in degraded listening environments, which is not the case for auditory trainers used as conventional hearing aids; that is, used with their environmental microphones. Consequently, the use of FM transmission in contexts where speech is presented in far-from-ideal listening situations allows for custom fitting with lesser chance of adverse effects on speech intelligibility.

The present findings also imply that the addition to a conventional hearing aid of an FM input, as offered by FM miniloop systems and direct audio input attachments, would give the personal aid all the efficiency of true FM trainers used in the FM mode to isolate speech from noise and reverberation in degraded listening environments.

Benefits of FM transmission, however, seem to be reduced under certain circumstances. Namely, high level total harmonic distortion (THD) paired with powerful amplication was believed to be the most significant element in this respect. Consequently, a careful evaluation of such a potentially disruptive combination would be advisable in the design of FM auditory trainers ■

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