Preferred Listening Levels Among Personal FM System Users With Severe-to-Profound Hearing Impairment

Niveaux d'écoute préférés chez les personnes ayant une déficience auditive de sévère à profonde et utilisant un système MF

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ABSTRACT

Hearing aid (HA) and frequency modulated (FM) preferred listening levels were assessed among five participants with severe-to-profound hearing impairment. Participants utilized behind-the-ear HAs coupled to a personal FM (PFM) via direct audio input. Two amplification modes (i.e., HA microphone alone and FM microphone alone) and two listening conditions (i.e., in quiet and in competing noise) were investigated. High frequency average, peak, and overall RMS output, along with output at 500 and 1000 Hz were obtained from postlistening 2 cm^3 electroacoustical analyses. Results demonstrated that participants, in general, preferred statistically significant louder listening level outputs with their FM systems as indexed by high frequency average, overall RMS, 500 Hz, and 1000 Hz outputs ($p < .05$). Further, participants preferred the same output levels regardless of listening in quiet or noise ($p > .05$). The reason(s) for differences between HA and FM preferred listening level outputs remains to be found.

ABRÉGÉ

On a évalué les niveaux d'écoute préférés par prothèse auditive (PA) et par système de modulation de fréquence (MF) chez cinq participants ayant une déficience auditive de sévère à profonde. Les participants utilisaient une PA « derrière l'oreille » couplée à un appareil MF personnel (PFM) par entrée audio directe. On a étudié deux modes d'amplification (microphone PA seul et microphone MF seul) ainsi que deux conditions d'écoute (silence et bruits concurrents). L'expertise électroacoustique a tenu compte de la moyenne des hautes fréquences, du rendement maximal et du niveau de sortie RMS, ainsi que des rendement aux fréquences 500 et 1000Hz. Les résultats ont montré qu'en général, les participants préféraient des niveaux d'une importance statistiquement plus élevés avec leurs appareils MF, selon la moyenne en haute fréquence, les résultats RMS et les résultats à 500 et 1 000 Hz. En outre, les participants préféraient les mêmes niveaux de sortie, que ce soit en conditions de silence ou de bruit ($p > .05$). Il reste à expliquer les différences des niveaux de sortie préférés entre les appareils PA et MF.

KEY WORDS: preferred listening levels • FM system • hearing aid • output

Students with hearing impairment are often subjected to unfavorable listening conditions in the classroom. Specifically, signal-to-noise (S/N) ratios and reverberation times are often considerably less than optimal (Bess & Sinclair, 1985; Gengel, 1971; Hétu, Truchon-Gagnon, & Bilodeau, 1990; Sanders, 1965). Further, speaker-child distances constantly change, and as a result, the signal intensity delivered to the child's hearing aid (HA) fluctuates. Consequently, a student's carefully selected amplification may be rendered partially ineffective (Byrne & Christen, 1981; Plomp, 1978). A frequency modulated (FM) system, consisting of a teacher's microphone/transmitter and a student's receiver/amplifier, can provide greater signal constancy and ameliorate the effects of reverberation and noise by reducing the speaker-to-microphone distance (Byrne & Christen, 1981; Hawkins, 1984; Ross & Giolas, 1971; Madell, 1991; Picard & LeFrançois, 1986).

Audiologists should be aware of the many factors that affect the optimal benefit derived from FM systems (Ross, 1992; Stuart, 1989). One major concern is the provision of a consistent signal; that is, one in which the HA and FM output levels are matched (American Speech-Language-Hearing Association, 1994; Byrne & Christen, 1981; Hawkins & Schum, 1985; Lewis, 1991, 1994; Lewis, Feigin, Karasek, & Stelmachowicz, 1991; Seewald & Moodie, 1992).[1] In the case of a personal FM system (PFM), where a separate FM receiver is coupled to the student's HA, the environmental output received from the HA microphone should match the FM output transmitted to the receiver from the FM microphone/transmitter.

In order to achieve this consistent signal with a PFM, a number of factors need to be considered. First, the acoustic characteristics of speech of the FM versus the HA microphone differ due to speaker-microphone distances. The intensity level of speech input to the FM microphone may be approximately 15 to 20 dB louder because the typical speaker-microphone distance is approximately 20 cm, relative to one metre for the HA microphone (Byrne & Christen, 1981; Dunn & Farnsworth, 1939; Hawkins, 1988; Turner & Holte, 1985). Considering this, the gain of the FM system should be 15 to 20 dB lower (American Speech-Language-Hearing Association, 1994; Byrne & Christen, 1981; Hawkins & Schum, 1985; Lybarger, 1981; Lewis et al., 1991; Seewald & Moodie, 1992). Further, several studies have documented that the long term average frequency spectrum of speech also differs at these two microphone locations (Cornelisse, Gagné, & Seewald, 1991; Pearsons, Bennett, & Fidell, 1977; Turner & Holte, 1985).

A second factor is that one cannot assume that the electroacoustic characteristics of the HA are maintained when coupled to a PFM system. Differences in equivalent input noise, full on gain, and frequency response have been shown to exist when a HA is coupled to an FM system versus the HA alone condition (Hawkins & Schum, 1985; Hawkins & Van Tasell, 1982; Thibodeau, 1990).

A final concern regards the validity of the assumption that the listener would prefer the same output levels in the ear canal regardless of which device he/she is listening through (American Speech-Language-Hearing Association, 1994; Byrne & Christen, 1981; Hawkins & Schum, 1985; Lewis, 1991, 1994; Lewis et al., 1991; Seewald & Moodie, 1992). Some individuals may prefer more or less gain for the environmental or FM inputs, depending on the listening environment. For example, the listener may prefer the FM output to be louder relative to the environmental HA output.

Considering the number of factors that affect environmental HA and FM outputs, and in turn, achievement of a consistent signal, one may speculate that differences in HA and FM outputs for PFM users exist. There is a lack of investigations of the relative similarities/differences in preferred HA and FM output among personal FM users. The purpose of this study was, therefore, to investigate electroacoustically the differences between the environmental HA and FM outputs, at preferred listening levels, among PFM users in listening conditions of quiet and competing noise. The amplification modes include: HA microphone alone and FM microphone alone at preferred volume settings.

Method

Participants

Five students with hearing impairment, who utilized PFM systems in their educational setting, served as participants. They ranged in age from 9 to 26 years. Four of the participants were mainstreamed junior high students, and the one

Table 1. Audiological and Amplification Information for the Five Participants.

Participant	Age (year; month)	Pure-Tone Average	Years of Hearing Aid Use	Years of FM System Use	Hearing Aid Model
1	9;0	71.7 (R)	7	3	Unitron UE10
2	9;2	96.7 (R) 93.3 (L)	6	5	Unitron UE12PP
3	9;10	81.7 (R) 80.0 (L)	6	4	Danavox 133PPAGC
4	11;3	66.7 (R) 76.7 (L)	10	6	Unitron UE10
5	26;4	98.3 (R) 95.0 (L)	13	5	Unitron US80PPL

Notes: Participant 1 was monaurally aided; Pure-tone averages were calculated from thresholds at 500, 100, 2000Hz; R = right ear and L= left ear.

adult participant attended university. All participants had severe-to-profound hearing impairments (Yantis, 1994). Audiological information for each participant is presented in Table 1. All participants presented with no other disabilities.

Behind-the-ear HAs coupled to a PFM via direct audio input were utilized by all participants in their educational setting. Each participant had the HA switching options necessary to achieve the amplification modes of HA microphone alone and FM microphone alone. All participants were binaurally aided, with one exception. They were judged to be experienced PFM users, defined as those individuals who were able to actively manipulate the volume control settings to their preferred listening levels.

Apparatus

Testing was conducted in a double-walled sound-treated audiometric test room (Industrial Acoustics Corporation) meeting specifications for permissible ambient noise levels (American National Standards Institute, 1991). Two loudspeakers (Grason Stadler Model 162-4) were mounted in the test room with the diaphragm centre at a height of 1.1 metre. The test position was located at a height of 1.1 metre, and 1.3 metre from each loudspeaker. The orientation of the speakers to the test position was 0° and 180° azimuth.

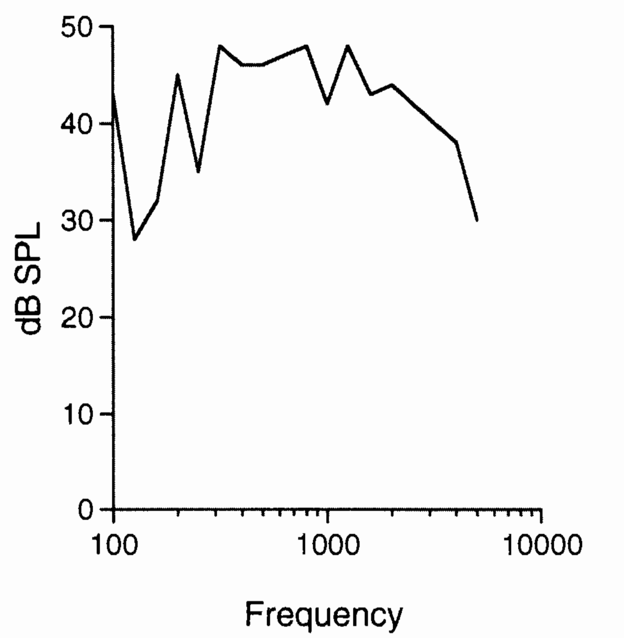
In the HA condition, participants were seated on a soft-backed office chair with a fixed seat height of 40 centimetres with their respective HA(s) in place. Actual head height position varied slightly around the test position. In the FM condition, the FM microphone was mounted on a microphone stand in the test position, in accordance with the Lewis et al. (1991) recommendation. Participants, wearing the FM receiver and HA(s), sat outside the test room with the experimenter. In no case did feedback limit participants' choice of volume control setting.

Recorded male talker connected discourse (Auditec of St. Louis, Inc.) served as the speech stimulus. It was routed from a tape deck (Akai Model GX-R66) through a clinical audiometer (Grason-Stadler GSI-10 Model 1700-9700), equalizer (Yamaha Model EQ-500U), and amplifier (Tecron Model 5507) to the loudspeaker located at 0° azimuth to the test position. A speech weighted composite noise served as the competing noise stimulus. It was generated by the Fonix 6500 Hearing Aid Test System and routed through the clinical audiometer, in a manner similar to the speech stimuli, to the loudspeaker located at 180° azimuth to the test position.

In the HA condition, the continuous discourse was presented at an intensity of 70 dB SPL for both quiet and competing noise conditions. In the FM condition, the input level of the continuous discourse to the FM microphone was 90 dB SPL for each listening condition. This is consistent with studies that have documented the level of the input to the FM microphone to be approximately 20 dB louder, relative to the hearing aid microphone (Byrne & Christen, 1981; Dunn & Farnsworth, 1939: Hawkins, 1988; Lybarger, 1981).[2]

For both HA and FM conditions, the intensity level of the competing noise was 55 dB SPL. This intensity is consistent with studies documenting noise levels in occupied classrooms (Bess, Sinclair, & Riggs, 1984; Blair, 1977; Pearsons et al.,1977). The presentation levels are also compatible with the +15 S/N ratio found in occupied high school classrooms for a HA microphone position (Pearsons et al., 1977). The spectrum of the competing noise, illustrated in Figure 1, was

Figure 1. Sound pressure level of competing noise spectra as a function of frequency.



shaped to approximate the average ambient classroom noise spectrum reported by Bess et al. (1984). The soundfield was calibrated according to procedures outlined by Walker, Dillon, and Byrne (1984).

A Fonix 6500 Hearing Aid Test System was utilized to analyze HA and FM systems. The system was calibrated, prior to testing, in accordance with manufacturer's specifications.

Both amplification systems were evaluated in a 2 cm^3 coupler since these measures are faster and more efficient than real ear measures (Lewis et al., 1991). The input stimulus for the electroacoustic analysis was a speech weighted composite noise generated by the hearing aid test system. The stimulus was composed of frequencies from 100 to 8000 Hz in 100 Hz intervals with a flat amplitude for the low frequency components and a slope of 6 dB per octave starting at 1000 Hz. This stimulus was employed in an effort to be more representative of the speech input to the participants' amplification systems during the experimental listening conditions (as opposed to a consistent level swept pure tone input). The input levels for the electroacoustic analysis were 70 and 90 dB SPL for the HA and FM systems respectively, consistent with the input levels present during the listening tasks procedure.

Prior to data collection, participants' HAs were electroacoustically analyzed (American National Standards Institute, 1996) to ensure that they were functioning according to the manufacturer's specifications. One Phonic Ear (471T/475R) PFM, functioning in accordance with manufacturer's specifications, was used by all participants in the FM amplification mode. The environmental microphone of the FM system was deactivated in the FM amplification mode.

Participants were instructed to listen to the recorded discourse for each amplification mode (HA microphone alone and FM microphone alone) for both the quiet and competing noise conditions. The participants were asked to adjust the volume of the HA/FM to a "comfortable" listening level from a preset minimum volume control wheel setting [3]. For the HA condition the participants adjusted the HA volume control while in the FM condition they adjusted both the HA and FM volume control wheels. Following each listening trial, the volume control wheel was taped and the HA and/or FM system analyzed electroacoustically. A hard copy of the Fonix 6500 Hearing Aid Test Systems' outputs was obtained for each test condition.

One practice trial preceded each test condition. The procedure was repeated once, resulting in a total of 16 trials for the participants who aided binaurally (two of each of the listening conditions [i.e., quiet and noise], amplification modes [i.e., HA and FM], trials, and ears). The remaining monaurally aided participant had eight trials. The listening conditions and amplification modes were counterbalanced across participants. The preferred listening levels from the two test trials were averaged for each participant.

Results

For each participant separate frequency response curves were obtained for each trial as a function of amplification mode and listening condition. High frequency average (HFA) output, peak output, overall RMS output (American National Standards Institute, 1996), output at 500 Hz, and output at 1000 Hz were obtained from each frequency response curve.

Prior to analyses of the total group data, separate paired t-test were employed to investigate differences between preferred listening levels in the right and left ears of the four binaurally aided participants. There were no statistically significant differences ($p < .05$) between the right and left ears for any of the test variables: HFA [$t\,(15) = -1.36$, $p = .19$], peak [$t\,(15) = -1.47$, $p = .16$], overall RMS [$t\,(15) = -1.60$, $p = .13$], output at 500 Hz [$t\,(15) = -0.99$, $p = .34$], and output at 1000 Hz [$t\,(15) = -1.24$, $p = .23$]. It was of no surprise that there were no differences between the preferred listening levels of the two ears of the four binaurally aided participants, as their hearing losses were essentially symmetrical (see Table 1). As there were no differences between ears, data from the two ears of the four binaurally aided participants were collapsed and averaged prior to further analyses.

The mean HFA output, peak output, overall RMS output, output at 500 Hz, and output at 1000 Hz as a function of amplification mode and listening condition are presented in Table 2. Separate two-factor analyses of variance (ANOVA) for repeated measures were undertaken to assess differences in mean HFA output, peak output, overall RMS output, output at 500 Hz, and output at 1000 Hz as a function of amplification mode and listening condition. A statistically significant main effect of amplification mode was found for each of the HFA output [$F\,(1,4) = 11.3$ Huynh-Felt $p = .028$, $\omega^2 = .63$], overall RMS output [$F\,(1,4) = 20.1$ Huynh-Felt $p = .011$, $\omega^2 = .76$], output at 500 Hz [$F\,(1,4) = 8.97$ Huynh-Felt $p = .040$, $\omega^2 = .57$], and output at 1000 Hz [$F\,(1,4) = 8.67$ Huynh-Felt $p = .042$, $\omega^2 = .56$]. Differences in peak output were marginally nonsignificant [$F\,(1,4) = 5.16$ Huynh-Felt $p = .086$, $\omega^2 = .41$, $\phi = .41$ at $\alpha = 0.50$]. In general, as evidenced in Table 2, participants preferred higher output levels with FM system listening. A nonsignificant statistical difference in peak outputs, in spite of a large effect size, can be attributed to low statistical power with a small sample size (Cohen, 1988). A nonsignificant main effect of listening condition was found for each of the HFA output [$F\,(1,4) = .63$ Huynh-Felt $p = .47$, $\omega^2 = .00$, $\phi = .10$ at $\alpha = 0.50$], peak output [$F\,(1,4) = .084$ Huynh-Felt $p = .79$, $\omega^2 = .00$, $\phi = .057$

at $\alpha = 0.50$], RMS output [$F(1,4) = .53$ Huynh-Felt $p = .51$, $\omega^2 = .00$, $\phi = .094$ at $\alpha = 0.50$], output at 500 Hz [$F(1,4) = .59$ Huynh-Felt $p = .049$, $\omega^2 = .00$, $\phi = .099$ at $\alpha = 0.50$], and output at 1000 Hz [$F(1,4) = .82$ Huynh-Felt $p = .42$, $\omega^2 = .00$, $\phi = .11$ at $\alpha = 0.50$]. That is, participants preferred the same output levels regardless of listening in quiet or noise. Finally, a nonsignificant interaction of amplification mode by listening condition was observed for each of the HFA output [$F(1,4) = .35$ Huynh-Felt $p = .59$, $\omega^2 = .00$, $\phi = .079$ at $\alpha = 0.50$], peak output [$F(1,4) = 1.51$ Huynh-Felt $p = .29$, $\omega^2 = .078$, $\phi = .16$ at $\alpha = 0.50$], RMS output [$F(1,4) = .025$ Huynh-Felt $p = .88$, $\omega^2 = .00$, $\phi = .053$ at $\alpha = 0.50$], output at 500 Hz [$F(1,4) = 16$ Huynh-Felt $p = .71$, $\omega^2 = .00$, $\phi = .063$ at $\alpha = 0.50$], and output at 1000 Hz [$F(1,4) = 25$ Huynh-Felt $p = .64$, $\omega^2 = .00$, $\phi = .070$ at $\alpha = 0.50$].

Table 2. Mean High Frequency Average, Peak, and Overall RMS Output (dB SPL) as a Function of Amplification Mode and Listening Condition (n = 5).

	Listening Condition			
	Hearing Aid		Personal FM	
Parameter	**Quiet**	**Noise**	**Quiet**	**Noise**
High Frequency Average Output	106.8 (3.3)	103.7 (4.1)	113.6 (2.1)	114.1 (3.6)
Peak Output	113.1 (3.3)	109.9 (3.7)	116.2 (3.9)	121.0 (3.4)
RMS Output	105.0 (3.4)	105.4 (2.8)	111.9 (2.1)	112.7 (3.6)
500 Hz Output	95.2 (3.8)	93.2 (4.3)	100.4 (3.5)	100.2 (4.3)
1000 Hz Output	106.3 (3.8)	103.7 (5.3)	111.7 (3.6)	111.5 (4.0)

Note. Standard errors of the mean are presented in parentheses.

Discussion

The findings of the study suggest that PFM users with severe-to-profound hearing impairments preferred listening level outputs that are louder with their FM systems than with their HAs alone. The differences between amplification modes were approximately 7 dB (see Table 2). This was evidenced by overall RMS, HFA, 500 Hz, and 1000 Hz output. There was no difference among participants in their preferred listening levels while listening in quiet or in noise. These findings, on first inspection, seem to contradict the premise, in FM fitting, of matching output levels across amplification devices for hearing impaired listeners (American Speech-Language-Hearing Association, 1994; Byrne & Christen, 1981; Hawkins & Schum, 1985; Lewis, 1991, 1994; Lewis et al., 1991; Seewald & Moodie, 1992). On the other hand, it may be the case that participants matched output levels on some other parameter(s), as opposed to the five parameters explored herein, not extracted from the frequency response curves.

It can be speculated that the differences between HA and FM outputs reflect the listeners' practice of preserving a favorable S/N ratio when the FM and HA microphones are activated simultaneously. That is, listeners are more apt to wear the FM system with the HA microphone activated so that they can listen to both the FM input (usually the teacher) and to other speakers around them. In doing so, listeners may desire the FM output to be 5 to 10 dB higher than that of the HA microphone input. This practice is recognized and recommended when assessing coupler output of an FM system in the FM and environmental operations modes of operation (Lewis, Eiten, Hoover, & Stelmachowicz, 1998). No definitive conclusions can be made from these findings, however, as participants were not tested in the combined HA and FM mode.

We agree that, when setting output levels, one should strive to present consistent listening experiences across amplification devices for listeners with hearing impairment. It may be the case, however, that sophisticated listeners may manipulate HA and FM outputs across different listening situations. The extent to which this is possible depends on the listener's preference, degree of hearing impairment, elctroacoustic characteristics of both the hearing aid and FM system, and the coupling system employed. The availability of FM systems with automatic fixed environmental reduction in the combined HA and FM mode or systems with FM precedence provide an additional consideration. If in fact listeners prefer a louder FM input signal relative to environmental signal, these systems may be preferred as some reduction of the HA input occurs when there is input to the FM microphone. Additional research is needed to address this speculation.

Generalization of these findings is limited for several reasons. The first concerns characteristics of the participant sample. Given that the sample size was small ($n = 5$) and the participants had severe-to-profound hearing impairments, generalizations to other degrees of hearing loss and to the general PFM user population should not be made. Further research is warranted with a larger sample size which incorporates participants with varying degrees of hearing loss. The second factor relates to the test environment. It is evident that the artificial test situation may not accurately reflect that which is encountered in the classroom by students with hearing impairments. That is, students with hearing impairments may experience changes in teachers' vocal output and long term average speech spectrum, differing S/N ratios, and different competing noise spectra in the classroom. Under varying listening conditions such as these, preferred listening level outputs may change. Consideration should also be given to the nature of the listening task. Participants were instructed to adjust their HA/FM volume control wheel such that the output was comfortable. In the classroom, students may adjust their volume control wheels to a different criterion. That is, output levels may differ when the student is seeking an intelligible rather than a comfortable speech output. Further, preferred listening levels may differ in the classroom with the presence of visual input.

Listeners with hearing impairment often use HA microphone plus FM microphone inputs in the classroom. That is, students not only attend to the teacher's input to the FM microphone, but also to the input to the HA for auditory self-monitoring and interaction with peers in the classroom. Preferred listening level outputs for HA plus FM microphone may differ from HA or FM microphone alone. On both theoretical and practical levels, an additional concern has been raised by Rowson and Bumford (1995) in the incompatibility of equating FM and HA outputs while maximizing S/N ratio. In the combined listening mode, for greater HA/FM gain differences, smaller differences in HA/FM output will be experienced but at a cost minimizing the signal-to-noise ratio. Further research should assess preferred listening levels with this amplification mode.

Finally, one needs to recognize the difficulty of using speech weighted composite noise (as opposed to pure tones) as the input for the HA/FM electroacoustical analysis. Differences in frequency gain (output) characteristics may appear depending on whether measures are made with complex or pure tone inputs (Stelmachowicz, Lewis, Seewald, & Hawkins, 1990). Although a complex signal may have more face validity, as it is more representative of speech than a pure tone, when one listens to speech one rarely encounters a speech signal as wide in bandwidth as the speech weighted complex noise. The spectral characteristics of the recorded discourse falls somewhere in between that of the sweep tonal input and the broadband signal used in this study. Any attempt to evaluate preferred listening level outputs among participants may be compromised due to the fact that the input signals for the listening task and the electroacoustic analysis were spectrally different. That is, depending on the operating characteristics of the participants' amplification systems, (e.g., linear operating range, compression kneepoints, and maximum output setting) the resulting output levels may vary with recorded discourse versus speech weighted composite noise inputs (Stelmachowicz et al., 1990). The difference in output may not be important if one accepts that the electroacoustic analyses using speech weighted composite noise is only a 2 cm^3 coupler representation of how the HA/FM volume control wheels were set for the listening task.

In conclusion, the data demonstrate that listeners with severe-to-profound hearing impairment did not prefer, in general, the same listening level outputs across amplification modes. The reason(s) for differences between HA and FM outputs remains to be found.

Endnotes

1. In cases where the environmental microphone of either the HA or FM system and the FM transmitter microphones are activated simultaneously, it has been suggested that the FM output (e.g., the teacher's voice) be approximately 5 to 10 dB greater than the environmental output (Lewis, 1994; Lewis et al., 1998).

2. The input level to the FM microphone has been estimated to be as high as 90 dB SPL (Byrne & Christen, 1981; Dunn & Farnsworth, 1939: Hawkins, 1988; Lybarger, 1981) and as low as 80 to 85 dB SPL (Cornelisse et al., 1991; Hawkins, 1984, Lewis, 1991; Lewis et al., 1991). Depending of the value that one adopts the difference between the HA and FM input may range from 10 to 20 dB. In most cases it may be a moot point as signals above 75 dB SPL have little change in FM system output due to automatic gain control limiting in the FM transmitter (Seewald & Moodie, 1992).

3. The instructions given to each participant prior to the listening task were as follows: "You will hear a man tell a story. I want you to adjust the volume control wheel of your hearing aid/FM system so that the man's voice is comfortable.

Just think of comfortable as something you would want to listen to for a long period of time. This time, you will hear the man tell the story in quiet/noise."

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