CHAPTER 1

INTRODUCTION

1.1 : OVERVIEW

Many hearing impaired children have been provided with frequency modulated hearing aid systems (FM's) during recent years in the understanding that use of this technology will improve the reception of speech signals, thereby reducing learning deficits that may occur due to the hearing impairment. The need for systems such as FM's originates from the fact that hearing impaired listeners demonstrate decreased ability to understand speech relative to normal hearing individuals even when wearing adequately fitted hearing aids and operating in environments with the same signal-to-noise ratio and reverberation parameters as the normal hearers. As will be discussed later, typical classroom conditions, both in terms of noise and reverberation, have been shown to be such that speech reception by hearing impaired children in general, is significantly disadvantaged. In addition, the further the hearing impaired child from the source of the signal, the poorer the signal-to-noise ratio he/she receives at the ear.

Thus the basic design of FM's and similar classroom amplification systems aims to receive that speech which is of interest to the child, from a microphone situated close to the source, thereby ensuring a reduction of noise and reverberation relative to the signal, and transmitting this improved signal to the child.

However, in practice, the successful use of FM equipment involves a complex interaction between the features of the particular FM system being used, how and where it is being used, and by whom it is being used. More specifically the conditions needed for a particular FM system to be successful for the child include the following :

(i) no further distortion is added to the signal or accompanies the signal during its path from the source to the listener's auditory system, compared to the hearing aids alone.
(ii) the system is reliable over time and in the conditions it is used.
(iii) an improved S/N ratio is delivered to the ear relative to that which is obtained through the hearing aids alone.
(iv) the system significantly improves speech reception for the child in the situations where he would otherwise experience difficulty when listening through the hearing aids alone.
(v) the child finds the system acceptable to use and wear.
(vi) the teacher finds the system acceptable to use and wear.
(vii) the child and teacher are aware of how to use the system to advantage.

There has been little formal investigation of these factors and indeed only minimal evaluation of the type and degree of benefits obtained by hearing impaired children or the amount FM's are actually used by them. Given the considerable amount of resources necessary to implement and support FM fitting programmes, it would seem that an evaluation of present fittings could provide some valuable insight into planning effective provision of FM systems and improving services in the future.

Thus it is the overall aim of this study to attempt to construct a comprehensive picture of how well currently fitted FM units are meeting the needs of hearing impaired children and their educators, and to try to identify factors which significantly affect success of FM fittings. As part of this process some attention will be devoted to determining procedures which can be used for measuring FM gain and benefit in the clinic.

Initially, however, a review of the relevant literature on need for FM technology, features of current FM systems, and present evaluation of FM units will be presented.

1.2 : THE NEED FOR FM SYSTEMS

1.2.1 : The performance of hearing impaired listeners in conditions of noise and/or reverberation

One of the main complaints heard from hearing impaired adults, even those fitted with hearing aids, is that they cannot understand speech as well in noisy conditions as they can when it is quiet. Many researchers have verified that, due to the distortions created in their auditory systems because of their disorder, hearing impaired listeners are, in fact, at a greater disadvantage when in noisy and reverberant conditions, than are normal hearing individuals. For instance, Tilman et al (1970) compared the performance of normal hearing listeners with that of aided and unaided adults at various signal-to-noise ratios and equivalent sensation levels. Their data showed that the same noise levels which had only minimal effects on speech intelligibility scores for the normal hearing, led to very much greater disruption to speech intelligibility for the hearing impaired. Similarly, Finitzo-Hieber and Tilman (1978) tested 12 normal hearing children and 12 children with mild to moderate sensori-neural losses wearing their hearing aids in quiet and several signal-to-noise ratios in a monaural condition. The resultant monosyllable word discrimination scores shown in Table 1.1 also indicate the greater breakdown of speech intelligibility in noise for the hearing impaired group.

TABLE 1.1: Mean speech discrimination scores (%) for 12 normal hearing children and 12 children with mild to moderate sensori-neural losses wearing their hearing aids, in 3 signal-to-noise ratios. (from Finitzo-Hieber and Tilman, 1978)

	S/N ratio in dB			
	Quiet	+12	+6	0
normal hearing	95	89	80	60
hearing impaired	83	70	60	39

Further research has shown that hearing impaired listeners also suffer from greater susceptibility to increasing reverberation times (from 0.3 to 0.6 seconds-Nabalek and Pickett, 1974a, 1974b; from 0 to 1.2 seconds-Finitzo-Hieber and Tilman, 1978) compared to normal hearers.

To add even further to the difficulties of the hearing impaired, data by other researchers has suggested that the combined effects of increased noise and reverberation time act to cause greater deterioration in speech intelligibility than the simple addition of each effect on its own. The study by Finitzo-Hieber and Tilman (1978) mentioned earlier also looked at the effect of various reverberation times on speech discrimination scores in children. An extract from their results is shown in Table 1.2, revealing the synergistic effect of increasing noise and reverberation times. This relationship was also noted in the more recent data collected on adults by Nabalek and Mason (1981).

Table 1.2 : Mean speech discrimination scores (%) for 12 normal hearing children and 12 children with mild to moderate sensori-neural losses wearing their aids, in quiet, 3 S/N ratios and 3 reverberation conditions (from Finitzo-Hieber and Tilman).

	S/N Ratio in dB			
Reverberation time	Quiet	+12	+6	0
0.0secs	83	70	60	39
0.4secs	74	60	52	28
1.2secs	45	41	27	11

Thus the listening conditions considered by normal hearing listeners to be acceptable for speech understanding may not in fact be so at all for the hearing impaired individual. Gengel (1971) maintained that, according to his data using aided hard of hearing college students under moderate reverberation conditions (0.7 secs), hearing impaired listeners require S/N ratios of +15 to +20dB to receive speech adequately. In contrast this speech discrimination performance is possible for normal hearing listeners at 0 S/N ratios (Plomp, 1978). Also of interest is the fact that the negative effects of background noise and reverberation have both been noted to be greater in monaural than binaural listening conditions (Moncur and Dirks, 1967; Konkle and Schwartz, 1981).

The problem with most of the studies disscussed here is that they have not always used speech material that is representative of the type of listening tasks confronting hearing impaired children. Neither do they describe how listeners with greater degrees of hearing loss may fare in noisy and reverberant conditions. Nevertheless, it is clear that professionals dealing with hearing impaired children must be aware of the possible consequences of even minimal levels of noise and reverberation.

1.2.2 : Noise and speech levels in typical classroom conditions

A number of researchers have measured noise and speech signal levels in a wide variety of different classrooms. Unfortunately some of their results are difficult to compare as different frequency weightings have been selected. A summary of these measurements are shown in Table 1.3.

Table 1.3 : Reported measurements of classroom noise levels

Researchers	type of classroom	condition of classroom	levels in dB weighting		
			A	B	C
Watson (1964)	normal hearing primary	?			59
Sanders (1965)	normal hearing	unoccupied		55-58	
	units for partially deaf	"		42	
	normal hearing:				
	kindergarten	occupied		69	
	primary	"		59	
	high school	"		62	
	units for partially deaf:				
	all grades	"		52	
Paul (1967) cited in Ross (1978)	primary	?			63
Ross & Giolas (1971)	normal hearing	occupied			60

Pearsons, Bennett & Fidell(1977)	normal hearing	occupied	45-55		
Webster & Snell(1983)	hearing impaired tertiary	occupied	45-52		
Bess, Sinclair & Riggs (1984)	hearing impaired	unoccupied	41	50	58
		occupied	56	59	63
Denholme(1983) cited in Nolan & Tucker(1986)	normal	occupied	75-76		

Overall, Sinclair (1982) makes the following conclusions from this data : (i) classrooms that are specially designed for the hearing impaired are, on average, no quieter than classrooms used for normal hearing students (ii) occupied kindergarten and infants classrooms are more noisy than those of primary and secondary aged students (iii) no reduction in classroom noise levels has been shown over the last 20 years (iv) on average occupied classrooms range in noise levels from 59-63dBC , 42-69dBB, 45-76dBA.

Analysis of the frequency characteristics of this noise in occupied classrooms has indicated that it is speech-shaped (Sinclair, 1982)

Thus all of this research into classroom noise show levels well above those recommended by Fourcin, Joy, Kennedy et al (1980) who specified that classrooms for the hearing impaired should not exceed 30-35 dBA in order to create an acceptable listening environment.

Nevertheless, it is important to remember that the effects of these noise levels upon speech intelligibility depends on the accompanying signal level of the teacher's speech, that is, on the signal-to-noise ratio (S/N) that is present at the child's ear. This will in turn depend on two things : the actual speech level produced by the teacher and how far away the child is.

French and Steinberg (1947) found the overall average level of speech at one meter from the lips for conversation to be 60dBSPL but to increase to 69dBSPL in a lecture situation. Pearsons et al (1977) found average speech levels of teachers in classrooms to range from 67-78dBA, with an average of 71dBA when measured from one metre. But in reality, the level of speech at the listener's ear depends not only on the sound that is coming directly from the teacher, but also on the number of reflections of this sound from surfaces within the room that arrive at the listener's ear. As Niemoller (1981) explains, if the listener is within a certain critical range then the SPL from the source decreases by 6dB every time the listener is removed twice the distance from it. If he is further than the critical distance then the level he hears is the sum of the direct and reverberant sounds. This critical distance depends on the room acoustics - the more reverberant the room, the shorter the critical distance. In this way, the specific S/N ratio encountered is dependent on where the child is sitting relative to the teacher as well as the acoustics of the particular room. However, as has been pointed out earlier, the amount of reverberation not only adds to the level of the signal, but also creates increasing distortion the later these reverberated sounds arrive at the ear relative to the direct sound from the source. In this way, the specific S/N ratio encountered is dependent on where the child is sitting relative to the teacher as well as the acoustics of the particular room.

Another factor relevant to the issue of S/N ratios is the observation that the levels of speech signals are usually dependent on the level of noise present. Pearsons et al (1977) found that, on average, there was a dB for dB relationship between the level of the teacher's voice and the background noise. That is, as noise levels increased from 45-55dBA, teachers' voices rose concommittantly from 67-78dBA. This finding suggests that there should be an average S/N ratio in classrooms which is fairly constant, at least for particular teachers. Table 1.4 shows some average S/N ratios actually measured in classrooms from positions where children were seated.

Table 1.4 : Average S/N ratios measured in typical classrooms: A summary of research findings

Researchers	type of classroom	average S/N ratio
Sanders (1965)	normal hearing: preschool/infants primary/high school	 0 dB +5 dB
Paul (1967) cited in Ross (1978)	normal hearing: primary	+3 dB
Pearsons et al, (1977)	normal hearing at 2 meters from teacher	+15 to +16 dB
Bess & McConnell, (1981)	kindergarten & primary	-6 to +6 dB
Denholme (1983, cited in Nolan & Tucker (1986)	normal hearing	-10 to -5 dB

These measurements indicate considerable variation in S/N ratio with all except one study showing average values which are significantly poorer than that of the +15 to +20 recommended by Gengel (1971). One possible explanation for variation in the data between studies is location of the measurement point relative to the signal source. Only the Pearsons et al (1977) study specifies at what distance speech measures were taken, namely in this case 2 meters. The other studies may well have measured voice levels at a shorter distance from the source. There is no data available which suggests what is an average teacher-child distance for hearing impaired listeners but it is likely that this would vary widely depending on whether it was an integrated setting or not.

Also the Pearsons study did not actually measure the signal level at this distance but only estimated what it would be given the reading they obtained from a microphone worn at a known distance from the teachers' mouths. This method may have lead to some inaccuracies in levels quoted.

There is also an additional point to be made. In all these studies, measurement of classroom noise occurred during intervals when the teacher was not actually talking. Therefore the types of classroom noise that would contribute to the overall level measured in such studies would possibly originate from most of the following sources :

i) noise external to the classroom

ii) environmental sounds within the classroom, e.g. movement of chairs, paper, pens etc.

iii) children's voices responding to the teacher

iv) children's voices talking in the background.

However, the contribution of ii), iii) and iv) would be expected to be less when the teacher was speaking than when she was silent, so the noise level obtained during these silent periods would not be a true reflection of the actual S/N ratio when the speech signal was actually occurring. Accurate, simultaneous recording of noise and speech levels is not possible so the true S/N ratio eludes measurement. Thus it is possible that the S/N ratios reported in the literature are unrealistically poor.

Nevertheless, the expected average S/N ratio of approximately 20 dB, which the data of Pearsons et al (1977) suggests, does not seem to be in evidence.

1.2.3 : Typical reverberation times for classrooms

Reverberation is defined as "the time required for a specific sound to decrease 60dB in SPL after the source has been stopped" (Ross, 1978, p.472). Reverberation has been found to affect speech intelligibility in a similar fashion to masking noise (Sinclair, 1982).

Table 1.5 shows the results of several studies where reverberation times in classrooms have been measured.

Table 1.5 : Average reverberation times found in classrooms

Researchers	type of classroom	average reverberation time
Thomas (1960)	normal	1.3 - 3.4 sec
Tolk (1961, cited in Ross, 1978)	normal	1.2 sec
McCroskey & Devens,(1974 cited in Ross, 1978)	normal : rooms 40yrs old modern rooms	 1.0 sec 0.65 sec
Denholme(1981, cited in Nolan & Tucker, 1986)	normal	1.2 sec

As can be seen, measures of over 1 second are common, although there is some suggestion from McCroskey & Devens (1974, cited in Ross, 1978) that the situation is improving with lower reverberation times being attained in more recently constructed classrooms. Nevertheless, even these improved conditions are still allowing sufficient reverberation to significantly degrade speech intelligibility for hearing impaired listeners (Nabelek & Pickett, 1974a, 1974b; Finitzo-Hieber & Tilman, 1978). For instance, Table 1.2 shows there can be an average decrease of 9% in speech discrimination scores as reverberation times increase from 0 to only 0.4 seconds when the listener is situated in the fairly typical S/N ratio of +6dB, but a further devastating 25% drop in scores as the reverberation time extends to 1.2 seconds.

1.2.4 : Conclusions

Thus it is clear that, despite what is known about the disruptive effects of noise and reverberation, and despite the present acoustic treatment of classrooms even in special units, conditions still exist which significantly degrade the intelligibility of speech for hearing impaired children. This is additional to the discrimination loss that is present even in ideal listening conditions due to the nature of the hearing disorder.

Of course, S/N ratios and reverberation are not the only determinants of a child's understanding of speech in a classroom setting. Other factors include severity and type of hearing loss, the degree of correspondence between the language used by the teacher and language competence of the child, articulatory factors in the teacher's speech, availability of visual cues and motivational effects. In addition, it is expected that a hearing impaired child who is faced with hearing new language as well as having to assimilate new academic material would find classroom conditions more disruptive to comprehension than would a hard of hearing adult in similar situations due to his lower level of competence with the language (Olsen, 1977; Ross, 1977)

Nevertheless, it would be predicted that improving the S/N ratio and reverberation conditions to allow the child to perform at optimal levels within these constraints will improve his educational chances and, in fact, is the responsibility of the audiologist in his aim of providing the amplification system which will most benefit the individual and his situation. For these reasons it is necessary to create and evaluate FM amplification systems to ensure they are fulfilling this aim.

1.3 : DESCRIPTION OF FM SYSTEMS

1.3.1 : The principle of microphone proximity to the source

It has long been appreciated that moving the microphone of the amplification device closer to the speaker will result in an improvement in S/N ratio and an increase in the direct component of speech relative to the reverberant component. The signal becomes louder relative to the background noise and the reverberation effects become less significant if the microphone is placed in the direct field which is usually within one meter from the source (Pearsons et al, 1977). Ross (1978) summarises the findings of 10 researchers who found significant improvements in speech discrimination as distance from the speech source progressively decreased, despite different test conditions, noise, reverberation and subjects. Thus the improvement in speech intelligibility with greater proximity of the microphone to the source is a very robust effect. Group amplification systems all take advantage of this situation by placing the microphone closer to the teacher than the child's ear.

1.3.2 : Traditional types of classroom amplification systems

Early classroom amplification systems consisted of hard wired and induction loop devices. The more recent developments in technology include FM radio and infra-red systems. A survey in the U.S.A. by Sinclair and Freeman in 1981 showed that, at that point in time and in that particular country, FM radio systems coupled to personal hearing aids were the most commonly used type (31% of classrooms) followed by units which function both as FM systems and hearing aids (26%). It is evident from the latest literature about group amplification systems that the former type of FM system is probably in even more widespread use in present times. Since this type of classroom system appears to be the equipment of preference for now and possibly the future (Ross, 1986), the other types of systems will not be described to any extent here. Excellent detailed descriptions of such equipment can be found in a large number of publications (Ross, 1977; Davis and Hardwick, 1981; Boothroyd, 1981; Sanders, 1982; Bess & Logan, 1984; Ross, 1986). The reasons for the rise of the FM system as opposed to these other types of amplification systems is explained by their comparitive flexibility, mobility, portability, constant strong signal level, possibility for use of multiple channels in close proximity and their ability to be coupled with the child's own personal hearing aid, which has already been carefully selected to suit the individual hearing loss in terms of gain, frequency response and power (Davis & Hardwick, 1981).

1.3.3 : Characteristics of FM transmission

In FM systems the teacher or other speaker wears a microphone/transmitter unit that is close to her mouth, preferably within 6 inches as suggested by Ross (1978) and the child wears a receiver unit. They are linked by a frequency modulated signal broadcast by the teacher's transmitter and received by the child's unit if tuned to the same frequency. Although the strength of the carrier signal transmitted varies with distance from the transmitter, the audio signal frequency modulated onto the carrier can usually be picked up at full strength over a certain range, sometimes up to considerable distances. Theoretically there should be no interference from other radio equipment provided no other FM systems are being used within its range, or, if so, that appropriate channel selection has been organised. Every country has defined a band of frequencies solely devoted to this use for hearing impaired people. However channels must be sufficiently far apart to ensure high fidelity and in some countries the number and width of channels are inadequate for some educational situations (Burgess, Christen, Donald and Lowe, 1979). For this reason, one FM system, developed in Australia, has utilised the low frequency FM range created by induction field transmission. This requires fewer channels to be needed due to the rapid decay of carrier signal strength with distance up to about 12 metres, that occurs in this frequency range. In addition, a "capture effect" is created by this type of transmission whereby the receiver locks onto only the strongest signal, usually from the closest transmitter on the same channel. For these reasons, there are fewer concerns with interference from other FM equipment being used in the vicinity (Burgess et al, 1979).

1.3.4. : An examination of the features of presently available FM systems.

Current FM systems vary considerably as to the features they offer to the users. Some of these will now be discussed. A small body of research has looked at the effects of some of these various factors, although overall little is known about the way in which most of these features interact with the characteristics of the individual users and their situations.

(i) Receiver design : Most of the literature and research on FM systems deals with units where the FM receiver also functions as a hearing aid (self-contained FM receiver) That is, the receiver is responsible for amplifying the signal and delivering this to the ear and therefore must incorporate electroacoustic adjustments to suit the individual's needs. This signal may originate either from the FM microphone at the speaker's mouth, or from an environmental microphone on the individual's receiver unit depending upon which of these is selected.

Alternatively the more recent innovation is a receiver which operates purely to accept the FM signal then passes this on, via one of several types of coupling alternatives, to the hearing aid(s) for appropriate amplification.

The latter types of systems have several advantages over the self-contained receiver system :

* improved flexibility and stability in individual selection of electroacoustic characteristics. Many problems with the self-contained systems such as electroacoustic performance variability both within and between units, have been reported in the literature (Ross, 1977; Van Tasell & Landin, 1980; Freeman, Sinclair & Riggs, 1980; Sinclair & Freeman, 1981; Bess, Sinclair & Riggs, 1984).

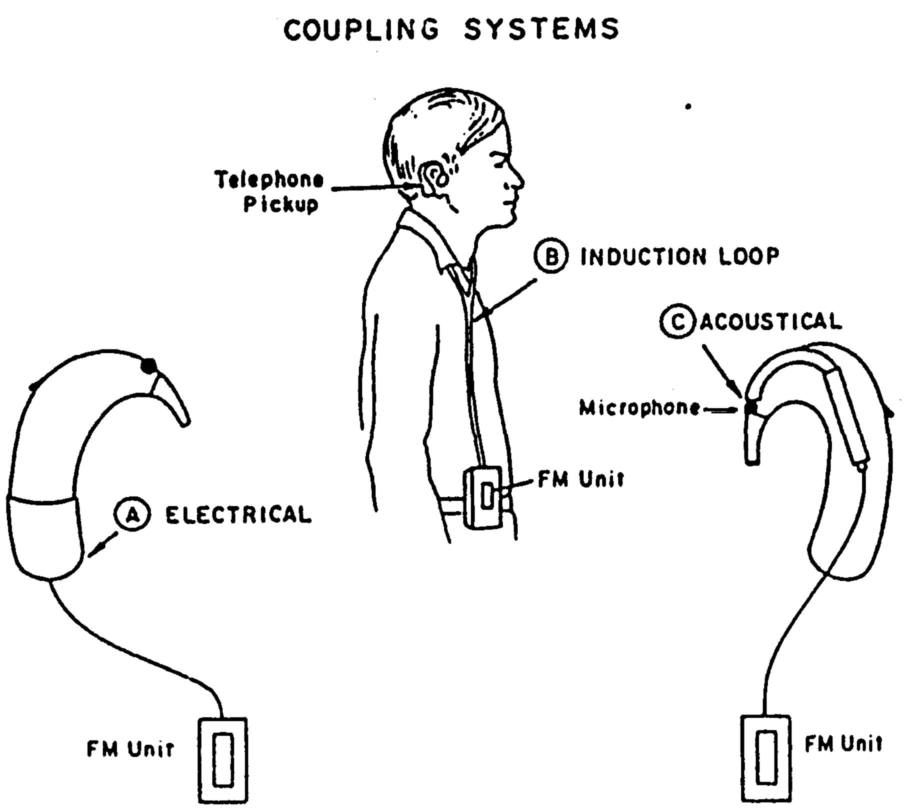
* ease of true dichotic binaural reception of environmental sounds and other speech which was difficult when using a body type aid (Ross, 1977)

* avoidance of having to wear a large body worn aid all the time

Thus the combination of a separate FM receiver with a personal head-mounted hearing aid would appear to be the preferred design according to the information available to date. However, there has been comparatively little evaluation of this type of system.

(ii) Method of coupling to personal hearing aid : Bess and Gravel (1981) describe 3 different methods of coupling or "dovetailing" the FM receiver to the child's personal hearing aids as shown in Figure 1.

Figure 1 : Illustration of three different methods of coupling the personal hearing aid to an FM system (from Bess and Gravel, 1981, p. 28)



(a) electrical or direct input coupling - In this method the output voltage from the FM receiver is delivered directly to the personal hearing aid via an input jack or "shoe" which fits over the bottom of the hearing aid. With this type of connection the gain of the hearing aid output may be controlled by more than one volume control ;

on the hearing aid itself or on the FM receiver.

(b) inductive coupling (or mini-loop) - This involves using a neck worn induction loop attached to the receiver. This provides an electromagnetic field which is then picked up by the hearing aid when it is switched to the telecoil position. However, unless there is an environmental microphone on the receiver itself, this method has the disadvantage of interrupting student to student communication and monitoring of the student's own voice.

(c) acoustic coupling - a small acoustic coupler, bringing electrical signals from the FM receiver, is fixed to the side of the hearing aid. This signal is then transduced and the acoustic signal fed into to the hearing aid microphone port by means of a piece of flexible tubing. The hearing aid microphone itself is not occluded thus allowing environmental sounds to be received normally.

Hawkins and Schum (1985) also describe a fourth method, a silhouette inductor, whereby the electrical signal from the FM receiver is directed to a thin inductor able to be worn over the ear next to the hearing aid, generating an electromagnetic field which can be picked up by the telecoil.

With the exception of the acoustic coupling method, all these options have been evaluated electroacoustically as to their effects on the hearing aid characteristics. Since the aim of all these coupling procedures is to ensure FM transmitted signals are presented to the ear with the individually selected amplification characteristics which are considered optimal, the coupling mechanism must be shown to not disrupt this matching of the aid to the wearer. However, overall research suggests that these electroacoustic characteristics cannot be assumed to have been preserved when the FM reciever is connected.

The inductive method has been shown to cause unpredictable alterations in frequency response when the hearing aid is set on telecoil (Matkin & Olsen, 1973; Van Tasell & Landin, 1980; Hawkins & Van Tasell, 1982) and variations in signal strength with changes in position or orientation of the head (Hawkins & Van Tasell, 1982).

The sillhouette inductor has similarly been found to cause significant increases in levels of harmonic distortion and internal noise when positioned, and to create changes in hearing aid output if minor movement of the inductor plate was allowed to occur (Hawkins & Schum, 1985).

Direct input coupling has been found to significantly affect the range of output levels from the hearing aid when attached in this way to the FM receiver. A range of 30 dB inputs was linearly amplified to an output range of 30 dB through the hearing aid alone, but the same range of inputs was compressed into only a 5 dB range of outputs when the FM was directly coupled to it (Hawkins & Schum, 1985). This would, however, be due to automatic gain control circuitry in the FM unit and, as will be discussed later, is not necessarily an undesireable feature.

Hawkins and Schum (1985) found that when direct input, neck loop and sillhouette couplings were used with a variety of hearing aids and FM systems, all 3 methods lead to changes in frequency response which differed depending on the combination of systems, but nevertheless consistently showed reduced high frequency output, compared to the hearing aids alone, of between 2 - 25 dB. These researchers also noted non-linearity of the FM volume wheel, the degree of which was dependent upon coupling method used.

However, Hawkins (1984) found that speech recognition in noise scores were not significantly different when direct input, sillhouette induction and neck loops were compared although only one type of hearing aid and FM system were used. In any case, there is still a need to examine how such alterations in hearing aid performance caused by its connection to an FM system, may affect speech intelligibility compared to the hearing aid on its own.

It is thus important that audiologists be aware of how they may be affecting their carefully selected amplification characteristics by connection to particular FM receivers and that such changes may have more effect on some individuals than others.

(iii) **Environmental microphone - FM microphone combinations :** The optimal amplification system for the hearing impaired child in a classroom situation includes not only the need for a consistent favourable signal level and S/N ratio for the teacher's voice, but also the facility to be able to hear the speech of his classmates and to monitor his own speech and its level (Christen & Plant, 1976). Some FM systems therefore offer the option of switching to an environmental microphone or microphones (EM) incorporated into the FM receiver or personal hearing aids. As mentioned previously, it is desireable if this is in the form of a true binaural arrangement such as can be offered by individually selected personal hearing aids worn on each ear. Some of the available systems allow either the EM or FM microphone to be selected depending on which suits the activities at hand, and some systems have the option as well of selecting a combined setting where both FM and EM are operating simultaneously.

However, a study by Hawkins (1984) comparing hearing impaired children's speech recognition in noise using an FM with direct input to a personal hearing aid in classroom conditions has suggested that simultaneous use of FM and EM causes most of the FM advantage found with the FM microphone alone to disappear. This is presumably due to increased level of noise relative to the teacher's voice which is heard when the EM'S are active. Such findings indicate that the voice operated (VOX) or signal operated (SOX) mechanisms available in a couple of the present day FM systems should be a solution which allows all 3 speech signals of interest to be received. The voice operated switch allows the signal from the FM transmitter to be received whenever speech from the teacher of a certain intensity is picked up at the FM microphone, after which the EM's are automatically muted to a significant degree. There is an unavoidable turn on delay before the FM signal is received, however. In contrast the signal operated switch is triggered by any speech or noise entering the FM microphone above a certain level and the only delay is in how long it takes for the hearing aid microphones to be muted since the FM transmission is not actually shut off in between trigerrings. Also, for both VOX and SOX systems there is a neccessary delay time following reception of the FM signal before the EM's are restored to full sensitivity to allow for pauses in speech. The effectiveness and acceptance of these systems have not been investigated in the literature.

Another important variable which has not been looked into is the question of ensuring if different modes of operation provide similar gain. At this stage it is not known whether it is desireable for such variation in output to exist as the settings are switched from the FM microphone only setting to the combined setting. Nor has it been determined what the relationship between EM and FM output should be to allow for optimal reception when using the combined mode.

(iv) FM microphone options : There are 3 different types of microphones which are found in current FM systems :

a) omni-directional b) directional c) noise cancellation systems.

The placement of an omni-directional microphone near the teacher's mouth will not prevent background noise being received and transmitted by the FM system, especially since the background levels will usually be fairly similar at this location to that of the EM. This means that when the FM only mode is selected, there may not be as large an increase in S/N ratio as might be possible and desireable from this microphone placement, although the signal itself might be at an ideal level. Hawkins and Schum (1985) predicted from their measurements that an improvement of between 4 and 7 dB in S/N ratio would be gained by using a directional microphone. In practice they found speech recognition thresholds in noise to show an average 3.3 dB increase, thereby supporting the use of such microphones with FM transmitters.

Byrne and Christen (1981) describe a noise cancellation system where a second microphone is employed and they maintain that this can bring about approximately a 10 dB increase in S/N ratio when speech is present.

It is also important to know whether differences in sensitivity exist between the various microphone options that may be available with a particular system so that gain can be readjusted for each to suit the listener.

In addition, FM systems vary in the styles of FM microphone they offer. Most systems have 2 options :

a) an on-unit microphone which is positioned by placing the transmitter around the neck

b) a lavalier microphone which is attached to the transmitter by a lead and can by worn clipped to the lapel.

There are also some headworn microphones available which have the advantage that the speech input level does not drop if the speaker's head is turned, since the microphone follows. However, there has been no data collected as to the effects of these different microphone arrangements on the signal heard. There is also a need to question users about the comfort and feasibility of wearing these microphones styles in classroom situations.

(v) Automatic gain control circuitry : To guard against variation in the level of speech coming into the FM microphone, automatic gain control (AGC) has been employed by most of the current FM systems. The threshold above which the compression circuit is activated must be adequate to cope with soft levels of speech yet not be triggered by other sounds entering the FM microphone. It is also necessary to have some knowledge of how the compression system in the FM unit may interact with any compression circuitry in the personal hearing aid to which it is connected (Hawkins & Schum, 1985).

(vi) Volume control characteristics : With some FM systems that provide coupling to personal hearing aids, there is usually more than one volume control that can influence hearing aid output. This may be on the receiver and/or transmitter (Bess & Gravel, 1981). Measurements by Hawkins and Van Tasell (1982) and Hawkins and Schum (1985) indicate that, when connected , and depending on the coupling method used, the FM volume control taper is far from linear. This means that to obtain a specific gain from the unit, the volume control wheel must be very carefully set.

(vii) Range of tramsmission : This needs to be selected so that it is sufficient to suit the situations where the FM is to be used. For example, assemblies and sports are two situations where considerable range would be desireable. However, there is no information available as to the amount FM's are used in such settings and what the exact range needs are.

(viii) Channel selection : Ease of channel selection is an important feature, especially in schools for the hearing impaired where children are listening to different teachers in a number of classrooms and sometimes changing rooms throughout the day. Most units therefore incorporate some frequency changing facility, usually in the form of an interchangeable crystal, although a dial selector would be simpler and has been employed recently. There also needs to be sufficient channel options available with the unit to satisfy the demands of such school situations (Burgess et al, 1979).

(ix) Batteries and charging facilities : Most present day FM systems are designed to use rechargeable batteries and usually provide a battery charger as part of the FM package. Ross (1986) recommends 8 hours of continuous use should be provided and low battery lights on the units ought to be included to warn when batteries are at the end of their charge. Some units do incorporate these.

(x) Auxillary input : Modern day FM's provide an input socket into which electrical signals from other audio devices can be fed. However, these facilities have not been evaluated as to their electroacoustic effects on the signal received by the listener. Some systems have the advantage of a talk-over facility whereby the teacher can interject by pushing a button during a programme.

(xi) Size and weight : There is some variability in both of these dimensions amongst current units. Obviously the aim is to design the smallest and lightest system possible for the comfort of the users. To some extent this will be determined by the number and size of the batteries required.

(xii) Options for wearing the unit : Most systems allow for either or both the transmitter and receiver units to be worn around the neck or on the waist, when combined with appropriate microphone styles. These allow flexibility to accommodate different individuals and situations. However, it is not known what users' preferences actually are.

1.4 : EVALUATION OF FM SYSTEMS

1.4.1 : Needs

As can be seen, the present generation of FM systems offer a diversity of options. However, very little research has focussed on the way in which hearing impaired children, their parents and teacher are using and benefitting from this technology in their day-to-day experiences. It is necessary to gain some knowledge as to how the features of FM equipment can be selected to provide an optimal system for any individual user, how well they are meeting present needs and what problems are experienced. It is also important to ensure that the services that are being provided by audiologists in fitting and supporting the use of FM units in schools are adequate to meet the needs of the teachers, parents and children who are using them.

The main factors which contribute to successful FM use have been listed in section 1.1. To thoroughly evaluate FM use and benefits, all of these areas need to be investigated in some way. However, although there has been discussion of these research needs in the literature, there has not really been any concerted effort to develop effective procedures to measure how successfully FM's are dealing with the problems of classroom listening conditions.

Nevertheless, there has been some consideration of the first 4 of these 7 factors in the literature, namely : whether use of FM units contributes any distortion to the speech signal received in the ear, how reliable the systems are over time, whether an improved signal is delivered to the ear relative to what is obtained through the hearing aids alone and how this significantly improves speech discrimination for hearing impaired children in classroom conditions.

1.4.2 : Distortion associated with use of FM equipment

The amplification characteristics that have been carefully selected for the individual to provide the most suitable speech signals should also be preserved when the FM system is in use. This means that the FM unit and its interaction with any personal hearing aid to which it is coupled should behave as if it is completely transparent to the signal. However, in the previous section this was shown not to be so. Depending on the equipment and the coupling method used, changes in frequency response, gain and input-output function have been noted (Hawkins & Van Tasell, 1982; Hawkins & Schum, 1985). Unfortunately evaluation of the electroacoustic properties of FM systems has been hampered by the lack of any standardised measurement procedures similar to those developed for hearing aid evaluation (Lybarger, 1981). This makes comparison of different FM aids and the effects of these on hearing aid frequency response difficult, confounds attempts to compare findings from different laboratories and complicates routine monitoring of equipment performance. A recent innovation by Hawkins (1987) involves the use of an ear canal probe tube microphone measurement system to assess the real-ear performance of FM systems, a technique which could prove useful in the clinic. However, it is beyond the scope of this thesis to include detailed discussion of electroacoustic evaluation techniques.

Nevertheless, on a more simple level, there is no information in the literature which identifies whether interference from other sources such as radio frequency equipment or clothing noise from the FM microphone is ever a problem, nor whether the subjective quality of FM processed signals is acceptable to users.

1.4.3 : Reliability of FM units

Surveys examining the status of FM systems have been carried out in the U.S.A.. Wilson, Clegg and Hoversten (1972, sited in Bess & Bratt, 1981) discovered variations in rechargeable battery life and lack of linearity of volume control. Hoversten (1981) reports 28% of FM equipment in his study requiring repair over a school year. Audiologists surveyed in this study reported frequent faults in cord terminals into receivers and battery life as problem areas. Bess, Sinclair and Riggs (1981, sited in Bess & Logan, 1984) found at least half the 117 units they examined showed some fault on visual inspection.

Thus, compared to similar surveys of hearing aids in educational systems, FM units, though larger and initially suspected to be more durable, are actually found to be no better than the reliability of personal hearing aids (Porter, 1973; Bess & Bratt, 1981; Dawson, 1987).

Such findings dictate the need for regular monitoring of FM equipment to ensure users are consistently able to obtain benefit from the system.

1.4.4 : Measuring FM advantage using behavioural measures

There have been surprisingly few studies which have actually attempted to verify that the expected improvement in speech intelligibility is brought about by use of FM units. Considering the inability of most devices to deliver signals with the same electroacoustic characteristics that were carefully selected as being most suitable for the individual, it is necessary that benefit is demonstrated to justify their use. In short, proving that particular FM units provide significant improvement in speech intelligibility for individual hearing impaired children is fundamental to how we approach all other aspects of FM use.

Table 1.6 summarises the most important research to date which has used speech discrimination tests to measure FM advantage.

As can be seen, all 3 studies show the FM systems used did bring about a significant improvement in speech intelligibility scores, despite differences in methods, subjects and equipment. It cannot be ascertained from the manuscripts whether, in the two studies by Ross and Giolas (1971) and Bankosi and Ross (1984), the environmental microphones were active during testing but the magnitude of the improvement in speech discrimination scores suggests that they were not. It is reassuring to find that the average FM advantage was found to be as much as 27% by Ross and Giolas, about 28% by Bankoski and Ross, and ranging from 16% to 32% by Hawkins (at least according to the equipment, set up,

Table 1.6 : Summary of research which has measured FM advantage using speech discrimination tests

Researchers	subjects	conditions	amplification	speech material	%scores using		
					usual h/a	FM only	FM+EM
Ross & Giolas (1971)	13 h/impaired children, 10-18 yrs 7 aided + 6 unaided mild-severe losses	in classroom with ambient noise 60dBSPL	self-contained with binaural environmental microphone	live-voice PBK monosyllables at 65 dBSPL	32 normals = 91%	59	
Bankoski & Ross (1984)	9 h/impaired adults, mild-severe losses, 3 binaural h/a 3 monaural h/a 3 unaided	auditorium with poor acoustics	self-contained FM, 2 types	Tri-word test of intelligibility, 150 words at 70dBSPL on tape	47-64 normals = 63-68	FM1= 63-84 FM2= 78-88	
Hawkins (1984)	9 children with mild/moderate SN losses	classroom, 0.6 sec reverberation time, speech noise at +5 and +15 S/N	FM receiver connected to personal hearing aids	taped PBK monosyllables	+6dB S/N 44 +15dB S/N 64	 76 80	 56 72

materials and conditions each has used). However, as Hawkins (1984) points out, the degree of improvement can depend on at least 2 factors. If the environmental microphone is activated, there is less improvement compared to the hearing aid alone condition. This is further demonstrated by Hawkin's additional data where an adaptive speech test was used which entailed varying the noise level while the stimulus level was held constant at 65 dBSPL, until a S/N ratio was found (measured at the child's ear) where the subject reliably showed a 50% speech identification performance. The mean advantage for FM went from a 12-18 dB improvement for FM microphone only, down to only 2-4 dB for the combined microphone condition. These results were obtained even though the FM only condition was measured with a monaural hearing aid and some of the combined FM+EM conditions were with binaural hearing aid input to the ears. The other effect on degree of FM advantage was the S/N ratio, which, as it became poorer, caused the advantage to increase from 16% at +15 dB S/N to 32% at +6 dB S/N in the FM alone condition. Thus it would seem that the poorer the listening conditions, the greater the benefit resulting from FM use. This result is expected because the S/N ratio improvement offered by the FM becomes greater as the S/N ratio becomes worse.

However, there is a need for similar quantitative data to be gathered in order that the effects of other factors such as severity of hearing loss on degree of FM advantage can be ascertained.

In addition, all these studies have only used word level tests that are not representative of the type of listening situation faced by hearing impaired children in educational settings. It would be of interest to be able to demonstrate the degree to which this advantage is carried over into listening tasks more typical of learning environments. Also the question of the reliability and sensitivity of traditional speech discrimination tests in measuring effects of different amplification devices has been called into question in recent times (Chial & Hayes, 1974).

Another way that some researchers have attempted to demonstrate FM advantage is by comparing the change in aided thresholds with and without the FM and predicting the audibility of the speech signal in each case (Turner & Holte, 1985). However this type of practice is confounded by the effects of the AGC circuitry which is present in most FM units. This means that any sound softer than the aided thresholds will not be audible to the listener but sometimes sounds louder than the aided thresholds may also not be heard if they occur simultaneously with other speech components which activate the AGC. This will also be different for speech signals as compared to pure tone sounds as the compression system will not act in the same way for each of these types of input (Tomlin & Dillon, 1986). Thus such evaluation methods will not be very accurate. For this reason it is vital that some clinical procedure be developed to allow the presence of FM advantage to be checked and quantified for individual fittings.

1.4.5 : Acceptance and use of FM systems

The improvement in speech intelligibility that is offered by FM units has thus been demonstrated by a few studies. However, there other practical hindrances involved in using FM systems that would trade off with this advantage. This is obvious from the fact that some children reject the use of FM's despite the advantages offered. Therefore there must be a set of individual and situational factors which interact with the particular FM system being used to modify its acceptance and use. Christen (1983) has been the only researcher to publish any data on this aspect of FM use. Using a questionnaire administered in interview format to 176 hearing impaired children, he identified that acceptance of FM units depended on educational setting, age and degree of loss. The younger the children, and/or the greater the hearing loss, the more likely they were to accept and use an FM system. Also children in integrated classes more readily accepted FM units than those in special classes or schools for the hearing impaired.

Other factors likely to affect both the teacher's and the child's overall impression of advantage would include comfort and convenience, self consciousness, motivation, degree of difficulty experienced under present listening conditions, communication mode used, audiovisual speech reception abilities, type of classroom activities and teaching style, time involved in setting up the system and reliability of the units. However none of these issues have been formally examined in the literature. In fact there is a conspicuous absence of any information as to how much FM's are actually used, in what situations and what problems are encountered.

1.4.6 : Fitting practices and procedures

The other area likely to affect the advantage gained from FM's involve the practices undertaken by the audiologist in fitting and supporting the use of the units. This includes what settings are recommended, how comprehensive and appropriate the instructions are and how well the child, parents and teachers can be motivated to use the system.

The client controlled settings for any particlular system usually involve an FM volume control wheel and various FM only and combined EM/FM modes. Usually the hearing aid settings have been positioned to amplify conversational speech (commonly received at about 70 dBSPL from one meter by hearing impaired listeners, Byrne, 1979; Byrne & Cotton, 1987) so that optimal real ear levels are received at all frequencies according to the requirements of the selection procedure used. Ideally this should mean that the MCL of the listener is not exceeded nor the hearing aid put into saturation (unless it is already worn this way to achieve adequate sensation levels). Therefore most researchers agree that when the signal from the FM microphone is received, the FM volume control should be set so that the hearing aid output remains unchanged (Byrne & Christen, 1981; Hawkins, 1984). This requires that the system be measured to acheive this level, taking into account the effects of the AGC circuitry which acts differently on speech than on the pure tone stimuli usually used to measure gain of electroacoustic equipment (Tomlin & Dillon, 1986). Thus the output from the hearing aid of a 70 dBSPL speech signal presented to the hearing aid microphone must be adjusted to be the same as a typical speech input to the FM microphone (usually about 85 dBSPL - Byrne and Christen, 1981) by setting an appropriate FM volume level.

However, the way that required hearing aid gain is prescribed for hearing losses of a certain magnitude is based on data obtained from the preferred gain levels used by hearing impaired listeners wearing conventional hearing aids. There is no specific information available as to whether a different gain requirement exists for FM signals where background noise is less of a problem. Thus, although there does exist a rationale for setting FM volume that can be used clinically, the assumptions on which it is based have not been tested. Whilst exact volume control setting is not as much of an issue for older children since they will presumably set it as they find best, it is a problem in fitting FM's to younger children who are unable to comment upon or control the volume wheel setting and whose parents and teachers therefore require recommendation of an optimal level. In such cases it is also necessary to recommend the way FM only and combined microphone switches are selected if available so that these are used in situations where they are most appropriate and will provide greatest benefit.

Instructions must include full details of unit operation, battery charging, options for wearing the system and simple procedures to check it is working properly. In addition, it is necessary to provide guidance as to effective use in a range of situations. For instance, Ross (1977) has commented on the poor microphone technique observed in a number of teachers, and the negative effects of children being exposed to signals which are irrelevant to them because the teacher had forgotten to turn the unit off whilst talking to other children. It is also not uncommon for teachers and children to be happily using FM equipment which is later found not to be working at all. In fact, "correct utilisation of an FM auditory training system...in a classroom is often a pain in the neck" (Ross, 1977, p.241) and we are placing yet more demands on teachers who often have more than enough to consume time and attention. Also, older children must themselves spend time attaching and maintaining the units as well as putting up with another piece of equipment that visually demonstrates their disability. For these reasons, it is crucial that sufficient motivation and support be provided especially during the early weeks following fitting to ensure that problems are minimal and advantages are clearly revealed.

However, the effectiveness and adequacy of FM fitting procedures, vital in ensuring the system is utilised to its full advantage, has never been evaluated.

1.5 : AIMS OF THE PRESENT STUDY

The specific aims of this research project are multi-faceted and will be directed towards filling some of the many gaps that have been identified in the literature concerning FM systems.

There will be four main areas of study corresponding to four different experiments :

1. To measure the degree of FM advantage obtained using a listening task which is representative of classroom situations. For this purpose a continuous discourse tracking procedure similar to that proposed by De Filippo and Scott (1978) will be used over a number of sessions in actual classroom conditions. This procedure is well accepted as a measure used to evaluate effects of training and the use of varied amplification devices (for example De Filippo & Scott, 1987; Martin et al, 1981; Danz and Binnie, 1983; De Filippo, 1984; Owens & Raggio, 1987)

and is considered well suited to the aims of this study. Variables which may affect any degree of advantage shown will also be investigated such as degree of hearing loss, incorporation of visual cues into the task, and practice effects (experiment 1 - Chapter 2).

2. To provide further information about the users' subjective judgement of FM advantage in terms of improved speech intelligibility and to compare the benefits and acceptability to the listener of different FM and environmental microphone settings, microphone styles and FM volume settings. A paired comparison procedure will be used for this purpose as it combines the advantages of improved sensitivity to electroacoustic variables compared to traditional speech tests (Punch & Parker, 1981) and the opportunity to use connected discourse material as this is the usual type of signal received through FM system (experiment 2 - Chapter 3).

3. To attempt to develop a clinical measurement procedure which employs behavioural means to verify that the expected degree of FM advantage is being obtained from any particular system. Such a procedure is required in view of the inability to validly measure aided thresholds through an FM system, and the problems caused by lack of standardised electroacoustic means of comprehensively assessing individual FM systems. An adaptive speech testing procedure, similar to that used by Hawkins (1984), and carried out in noise, will be adapted (experiment 3 - Chapter 4).

4. To examine the use and benefit obtained from FM units that have been issued for some time. Information as to when, where and how much

they are used; how much benefit they offer in the eyes of the users and what behavioural differences are noticed as a result of using them; most commonly used settings; problems with consistency, malfunctions, maintainance and use; attitudes towards using the systems and adequacy of audiological advice and support will be gathered through questionnaire and interview data. In addition, the effect of factors such as age, degree of hearing loss, educational and communication programme and type of system will be examined. In this way it is hoped that a general impression of the adequacies and inadequacies of currently used FM systems in solving speech reception difficulties will be gained from the users themsleves, the teachers, parents and children (experiment 4 - Chpater 5).

CHAPTER 2

THE USE OF CONTINUOUS DISCOURSE TRACKING TO ASSESS DEGREE OF FM ADVANTAGE RECEIVED BY MODERATE TO PROFOUNDLY HEARING IMPAIRED CHILDREN IN CLASSROOM CONDITIONS

2.1 : RATIONALE

Whilst previous research has demonstrated that the use of FM systems creates significant improvements in word intelligibility (Ross & Giolas, 1971; Hawkins, 1984; Bankoski & Ross, 1984), no studies can be found in the literature which use listening tasks more typical of classroom situations. This study therefore aims to examine the extent to which these word discrimination effects are carried over into continuous discourse in actual classroom settings using FM systems as they are typically worn.

2.2 : METHOD

2.2.1 : Subjects

Twelve children attending a school for the deaf acted as subjects in the experiment. All the children in this school receive intensive language instruction using a combined oral/aural - cueing programme in the mornings and are then integrated in their local school in the afternoons. Age and degree of hearing loss for each child are shown in Table 2.1. All the children had sensori-neural losses.

Table 2.1 : Age and pure tone thresholds for the 12 subjects participating in the tracking experiment

Subject no.	Age in years	Ear	Pure tone thresholds (dB I.S.O)				
			0.25	0.5	1	2	4 (kHz)
1	7:3	L R	55 50	60 50	65 65	70 70	60 65
2	13:5	L R	40 30	60 55	70 75	80 80	80 85
3	8:5	L R	30 95	50 110	100 110	95 95	110 105
4	11:8	L R	85 85	90 95	90 110	90 115	80 120+
5	8:2	L R	105 80	110 85	100 95	105 100	105 100
6	13:9	L R	90 100	85 105	95 100	100 105	85 100
7	16:2	L R	- 60	- 95	- 100	- 105	- 90
8	11:7	L R	85 80	100 90	100 105	115 110	110 100
9	10:2	L R	100 90	105 95	105 110	115 115	105 120
10	8:5	L R	95 95	110 100	105 120+	105 120+	100 120+
11	10:3	L R	80 80	105 90	115 105	120 115	120+ 120+
12	8:3	L R	95 90	110 115	120+ 120+	115 120+	120 120+

The subjects were chosen to represent a range of hearing losses but were otherwise randomly selected from the school population. They were all using FM units daily in the mornings, and the majority were also wearing them every afternoon on school days.

2.2.2 : Equipment

The particular FM system used by all the children in this study is the induction field unit developed by the National Acoustic Laboratories. The distinctive features of this system are described in greater detail in Burgess et al (1979) and Byrne & Christen (1981) but briefly it is characterised by a short range 'capture effect' transmission, direct electrical input coupling to the hearing aids, choice of FM only, combined or VOX modes and omnidirectional microphone. The system was used on the children's usual settings, which in all cases consisted of a combined environmental microphone/FM microphone arrangement. The volume of the FM signal was set to point to a marker which indicated where the speech signal from the FM microphone provided the same level of output from the hearing aid as would a 70 dBSPL speech signal at the hearing microphone (see section 1.4.6). This corresponded with the volume setting the children usually used.

The FM microphone was the same as that used daily by the children's teachers, that is an omnidirectional lavalier microphone attached to the lapel at 15cm from the lips.

The hearing aids worn by the children were high powered Phonak PPC-2 or PPC-L aids , selected with the assistance of any necessary earmould modifications to provide the required real-ear gain specified by the Byrne & Dillon procedure (1986). All children were fitted binaurally with the exception of subject 7 who wears only one aid in the right ear.

All FM units and hearing aids were given their usual listening and functional check prior to each tracking session to ensure proper functioning. This involved the teacher listening through the FM system and each child's aid as well as having the child detect a number of phonemes from a distance once they had the system connected.

2.2.3 : Classroom conditions

The tracking procedure was carried out in the child's own classroom during a time when all children were engaged in individual activities at their desks. This involved the teacher and various teacher's aides assisting each child by answering questions and directing activity. This kind of lesson was a regular morning feature in each class and usually involved fairly constant speech from one or more individuals throughout the session. It was usually in this type of lesson that children were withdrawn into a corner by the teacher for individual speech or auditory training. In these situations the children usually had their FM's switched on. It was thus a typical listening environment for the subjects and a time when it was important that they were receiving an adequate speech signal in order to obtain benefit from the lesson.

Measurements of classroom noise present were made in 2 of the 5 classrooms where the testing was to take place, on a day prior to the commencement of the study, and when the teachers and children were participating in the same type of activities. A Bruel and Kjaer integrating sound level meter (module B2, 7100; Type 2231) with a 1/2 inch pressure microphone on the C weighting network was placed in the centre of the classroom for a period of 30 minutes. The C weighting was chosen as it would filter out very low frequency noise but yet would be most appropriate to the equal loudness curves that hearing impaired children would be likely to possess. The resultant Leq sound pressure levels were 65.7 dBC in one classroom and 66.4 dBC in another.

In addition, during all test sessions, a B&K sound level meter (type 2206) was set up in front of the experimenter and equidistant with the child's ear, on the C weighting network and fast response time. Visual inspection of the meter during test sessions indicated similar average noise levels to those found earlier.

The child and experimenter sat towards the back or front of the classroom where the individual auditory training sessions usually took place. The child sat with his back to the class, one metre from the experimenter, a similar distance to that usually observed in these types of lessons. The researcher used the same SLM to monitor her voice level during tracking to ensure a reasonably constant level of 65-70 dBC in all conditions.

2.2.4 : Procedure

A modification of the tracking method proposed by De Filippo and Scott (1978) was adopted. This is a technique where a talker reads from a prepared text in segments and the receiver repeats back what he has understood the segment to be. If the repetition does not match the text exactly, the talker repeats or uses some other strategy to enable the listener to provide a verbatim repetition of the text. For subjects

1-9, this was carried out without lipread cues, the experimenter covering her mouth with a card. However, due to the poor language abilities and severity of hearing loss of subjects 10, 11 and 12, this was too difficult a task so visual cues were also allowed.

The reading material used was selected by the child's teacher as being of an appropriate level of difficulty for each individual child. This commonly was a reading primer that the childen had not yet seen.

Tracking sessions lasted for 10 minute periods during which the FM system was used for 5 minutes and the hearing aids alone disconnected from the FM for 5 minutes. The presentation of FM or hearing aid alone conditions first was counterbalanced amongst the sample so as to control for order effects. After a rest period, another 10 minute session was conducted, this time with the conditions in the opposite order as shown in Table 2.2. On another day, usually about a week later, the entire 20 minute procedure was repeated. For each 5 minute session, the number of words were counted and divided by 5 to obtain the words per minute score. Thus for each condition, scores for 4 separate tracking sessions were calculated.

Table 2.2 : Presentation order of conditions over tracking sessions

Order of 5 minute tracking sessions		
	6 children	6 children
Day 1	FM / no FM...break...no FM / FM	no FM / FM...break...FM / no FM
Day 2	no FM / FM...break...FM / no FM	FM / no FM...break...no FM / FM

The clarification strategies used to obtain verbatim responses were the same as those described by De Filippo and Scott (1978) except that if 3 clarification attempts failed with any one word, it was presented with visual cues. This was necessary as most of the children were found to become frustrated and anxious if they constantly failed to understand the word, endangering their cooperation for the rest of the session.

2.3 : RESULTS

2.3.1 : Degree of FM advantage

The tracking rates for each session achieved by each subject in the FM and hearing aid conditions are illustrated in Figure 2.1.

Means and standard deviations for each subject and condition as well as the differences between rates for each condition have been calculated in Table 2.3.

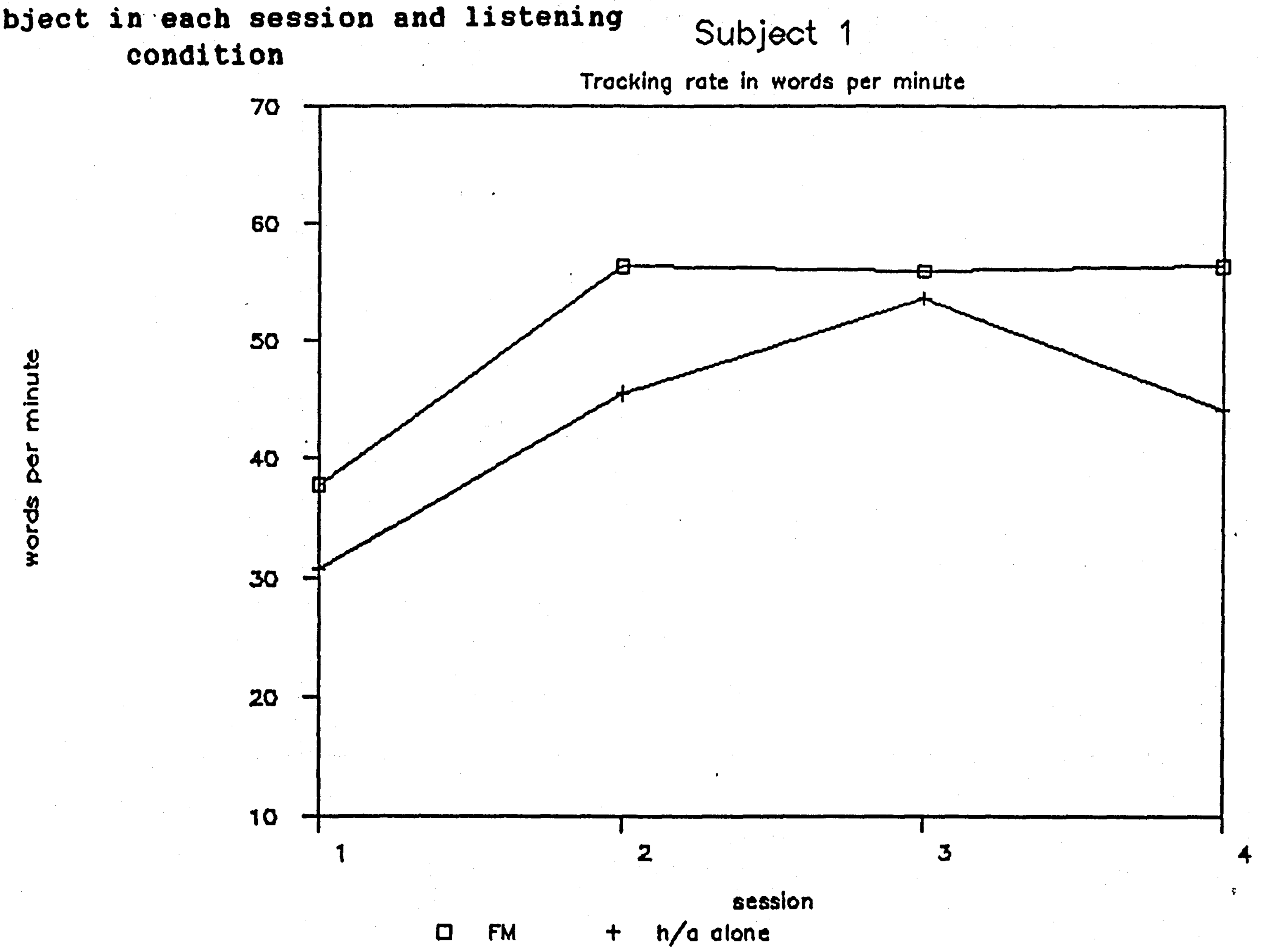
Table 2.3 : Mean words per minute for each subject in each condition and the difference between FM and hearing aid listening conditions

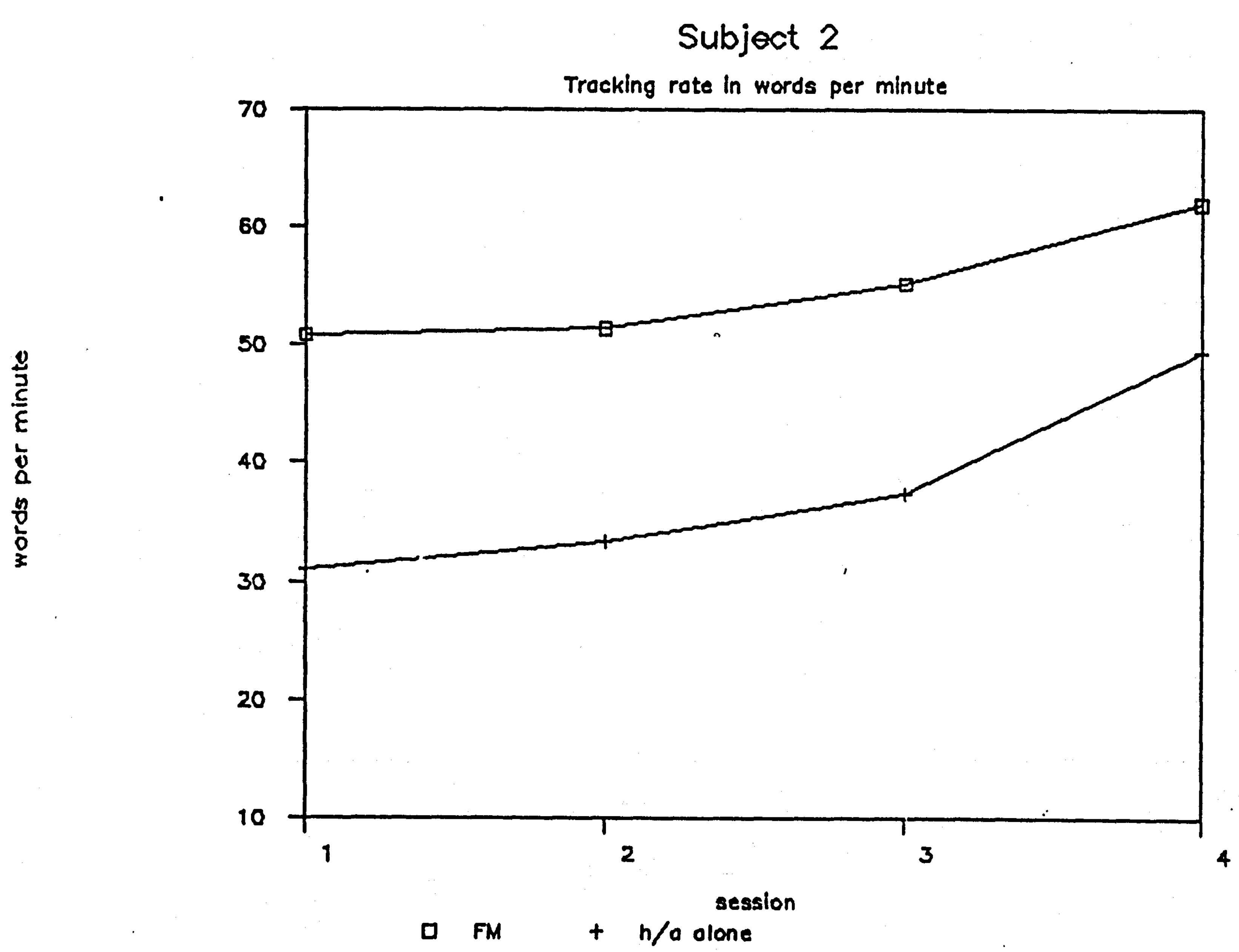
Subject no.	Mean words/minute			FM rate as a % of h/a rate
	H/A alone	FM	FM advantage (FM-h/a)	
1	43.55	51.65	8.1	18.6
2	37.8	54.85	17.05	45.1
3	28	38.15	10.15	36.25
4	26.85	36.45	9.6	35.75
5	17.92	28.2	10.28	57.37
6	31.55	40.6	9.05	28.68
7	18.85	21.45	2.6	13.79
8	12.15	16.8	4.65	38.27
9	18.95	27.9	8.95	47.22
10	39.3	41.8	2.5	6.36
11	34.1	38.5	4.4	12.9
12	41.6	38.3	-3.3	7.93
$\bar{x}$ =	29.22	36.23	7.01	
SD =	10.01	10.71		

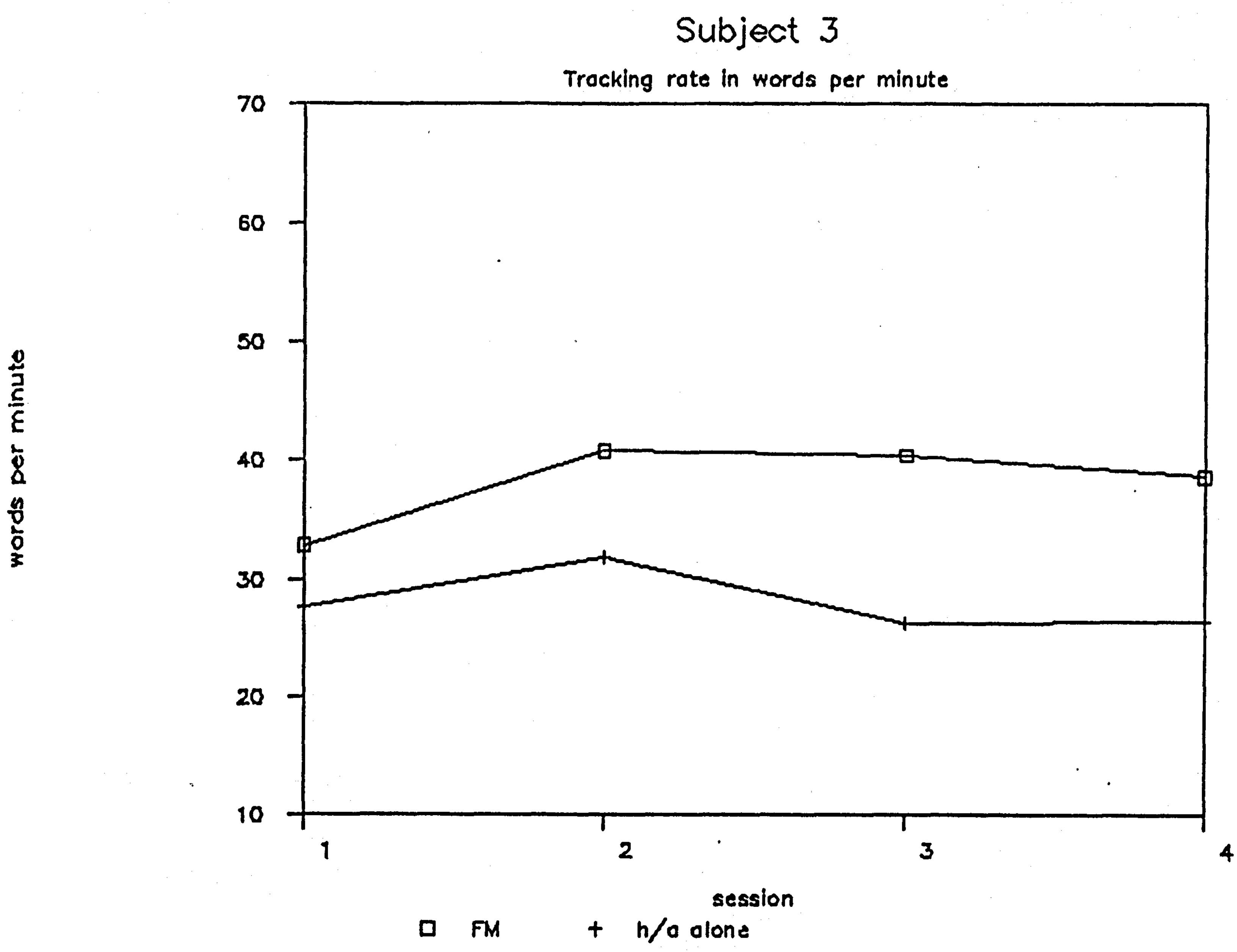
A paired t-test (one tailed) was carried out on the mean rates for each subject in each condition. A one tailed test was selected as FM rates were expected to be higher than tracking rates in the hearing aid alone condition. The results of this are shown below.

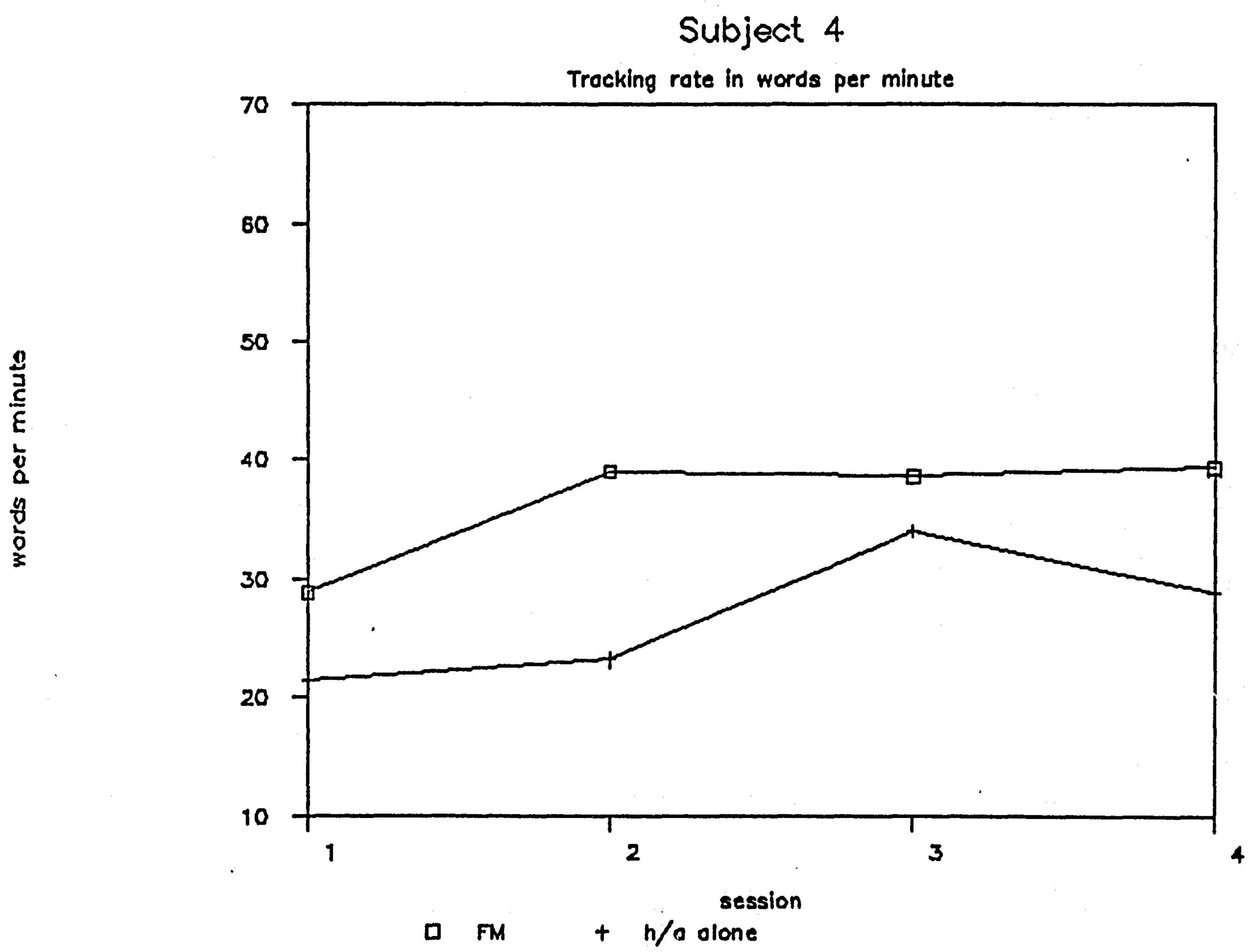
t= -4.682 (DF =11)
significant at 0.005 level

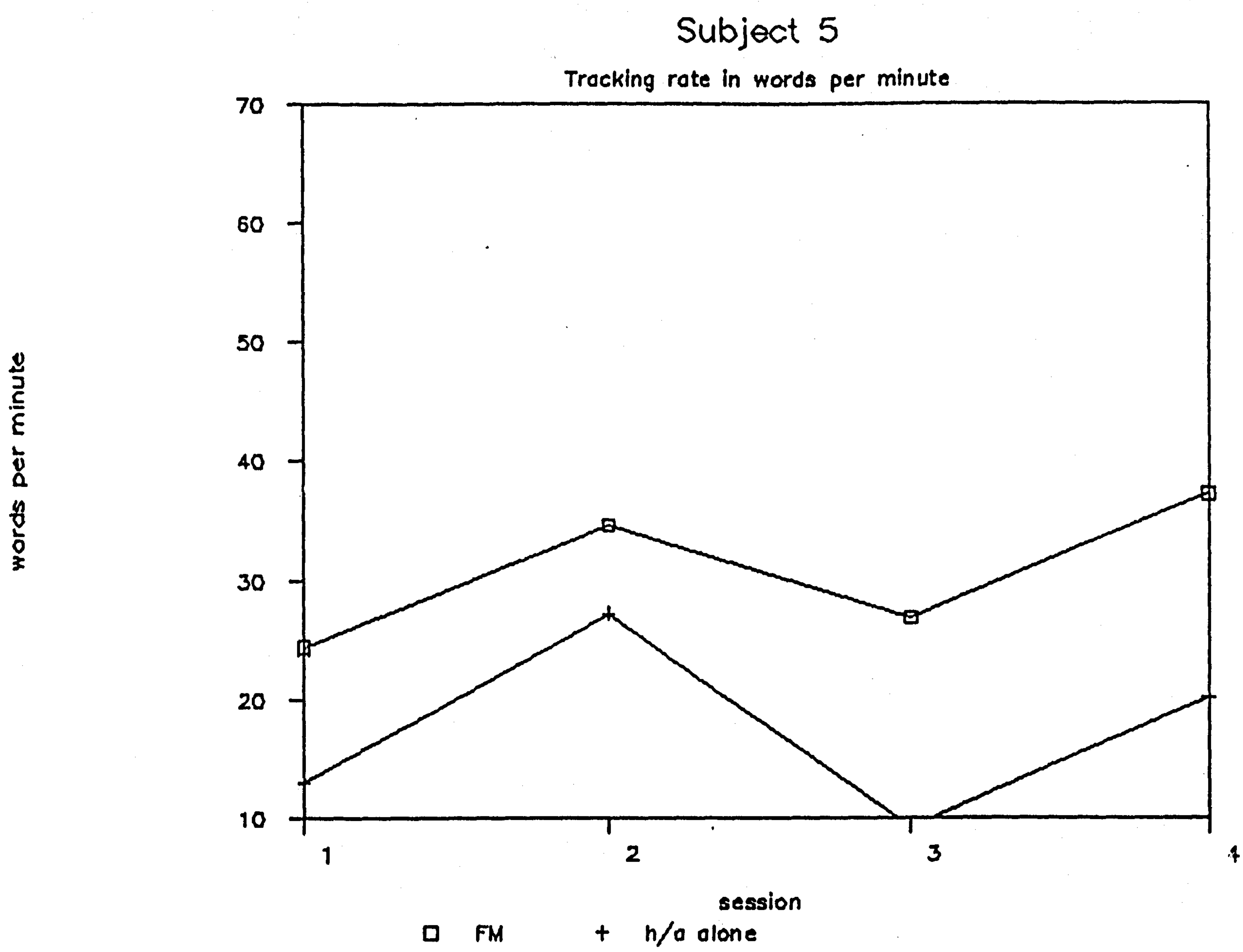
Figure 2.1 : Tracking rates for each subject in each session and listening condition

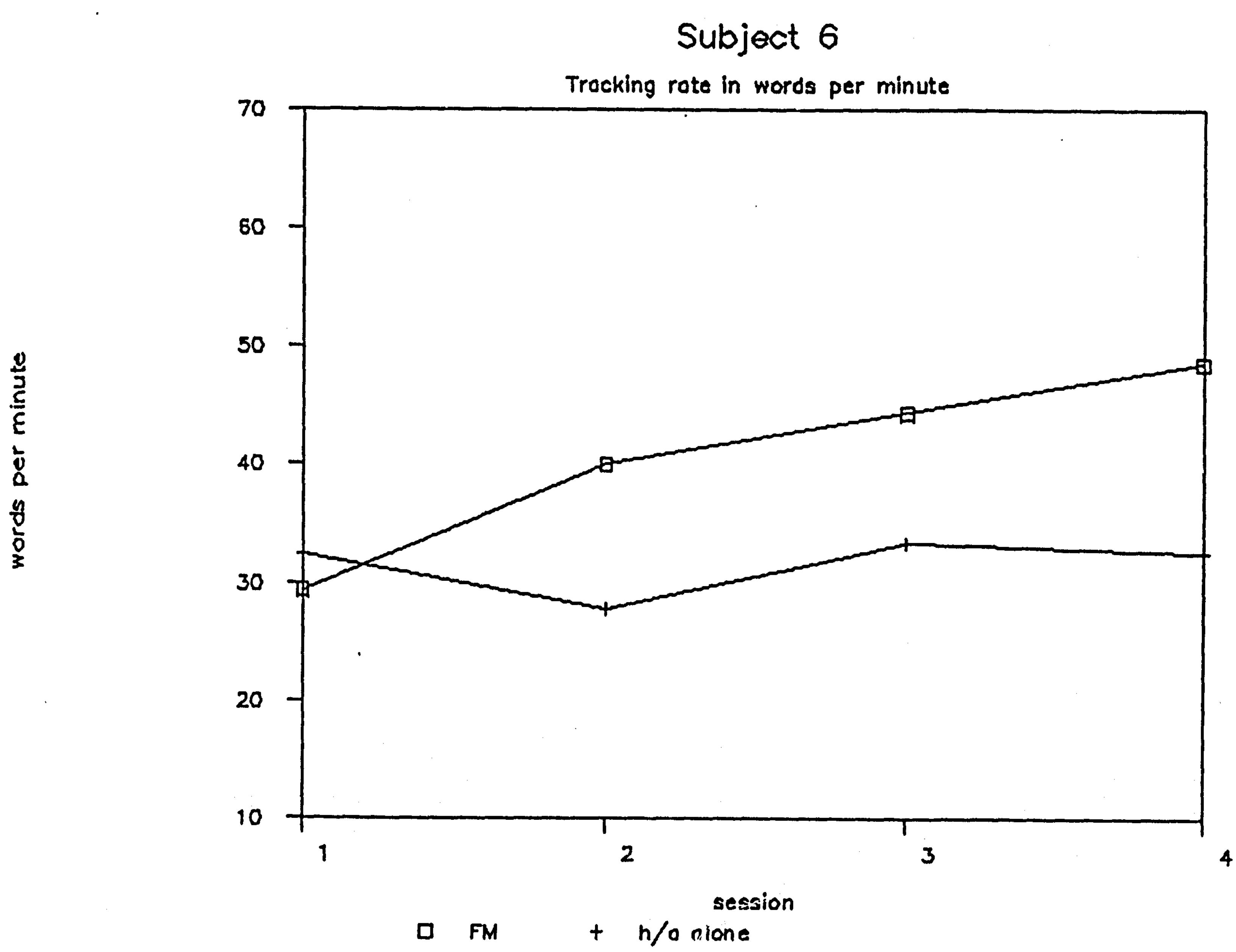


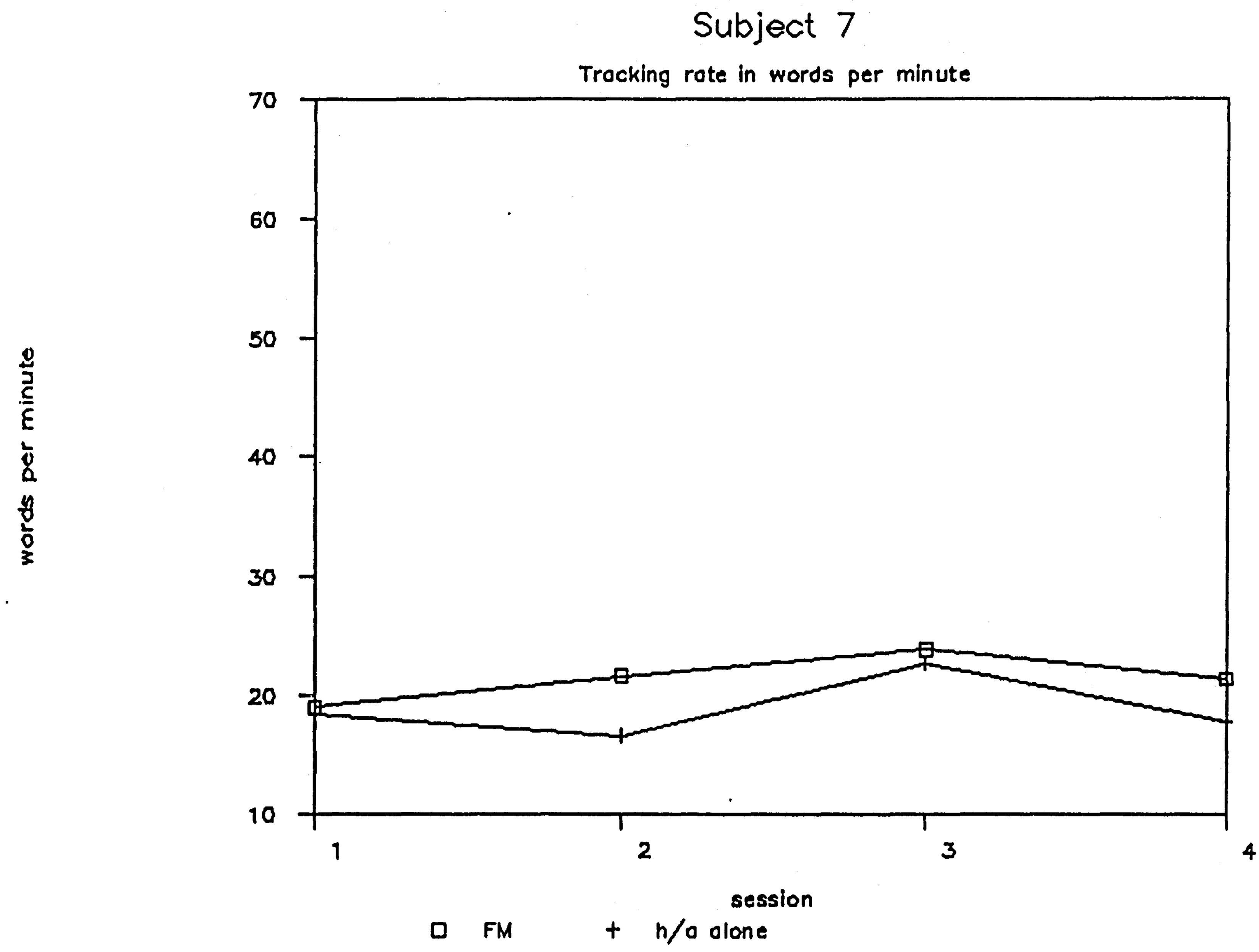


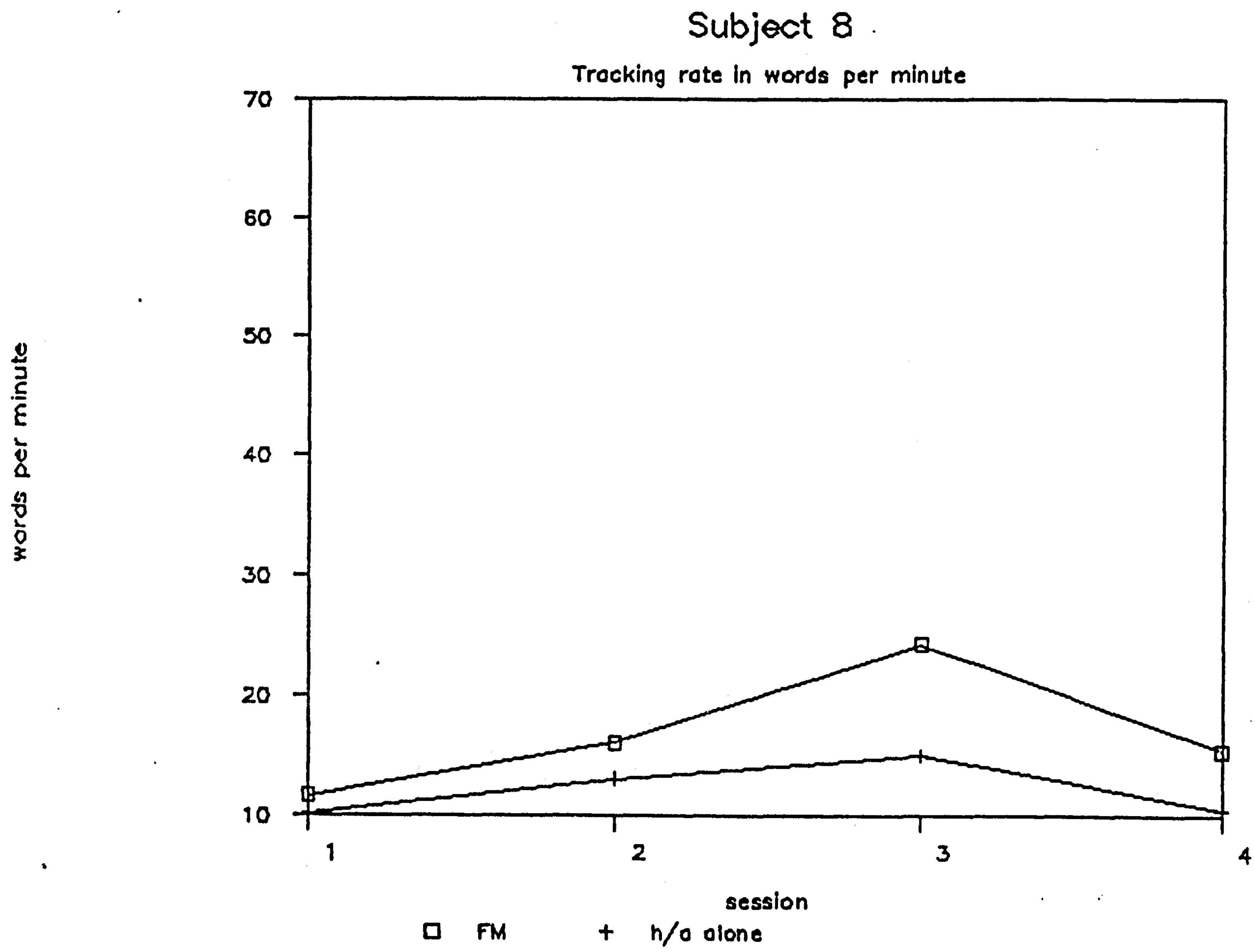

Subject 3
Tracking rate in words per minute
words per minute
70
60
50
40
30
20
10
1
2
3
4
session
FM
h/a alone

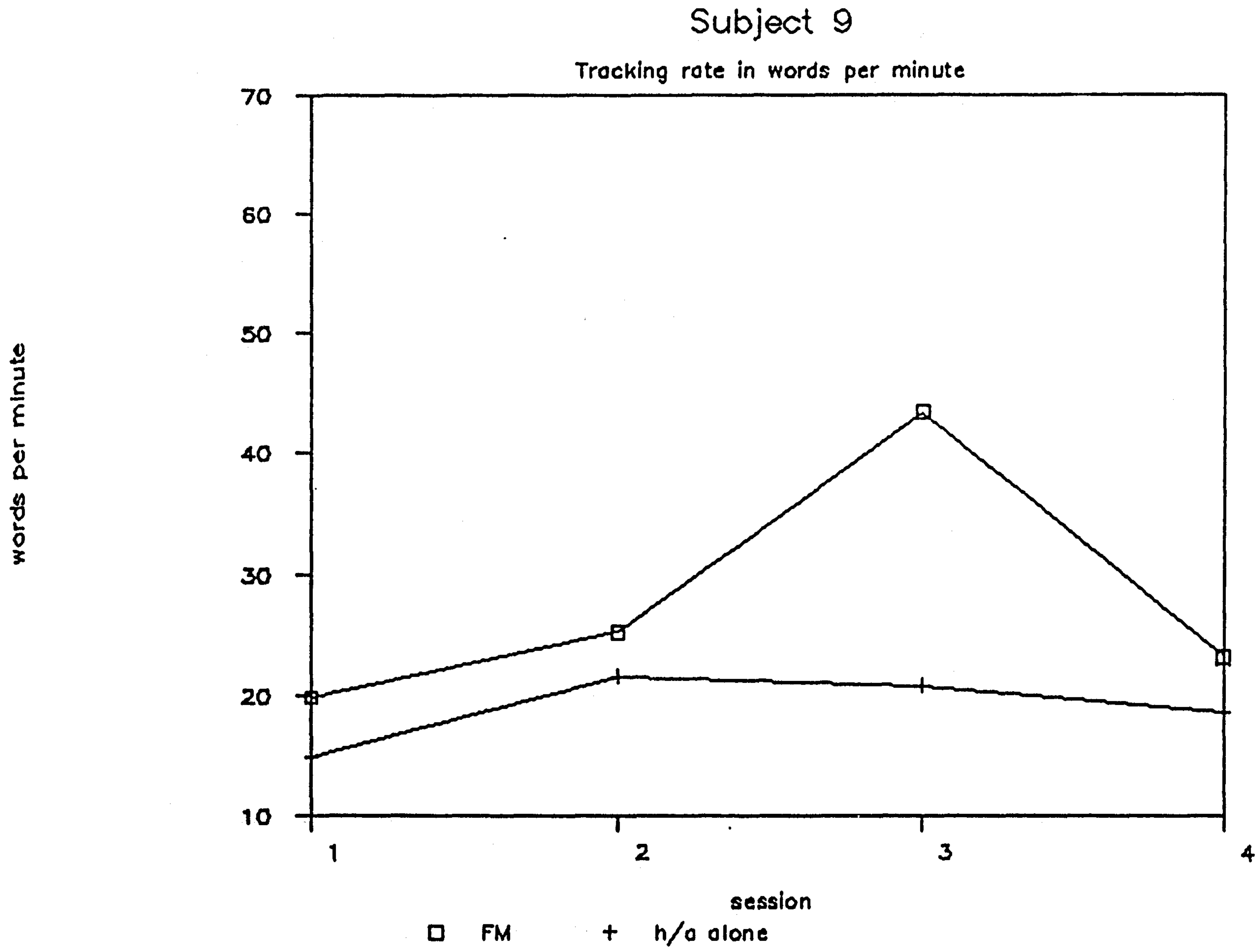

Subject 4
Tracking rate in words per minute
words per minute
70
60
50
40
30
20
10
1
2
3
4
session
FM
h/a alone

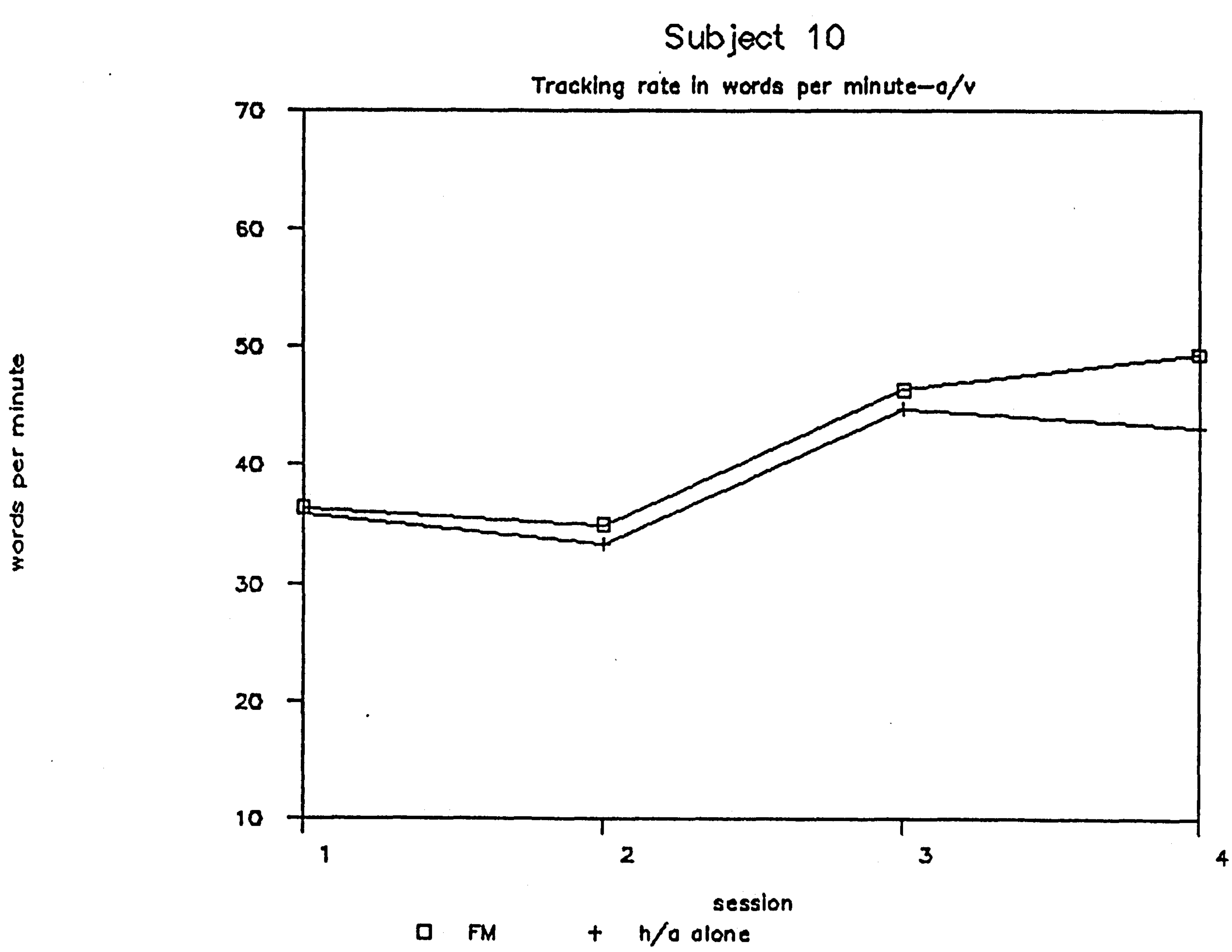

Subject 5
Tracking rate in words per minute
words per minute
70
60
50
40
30
20
10
1
2
3
4
session
FM
+ h/a alone

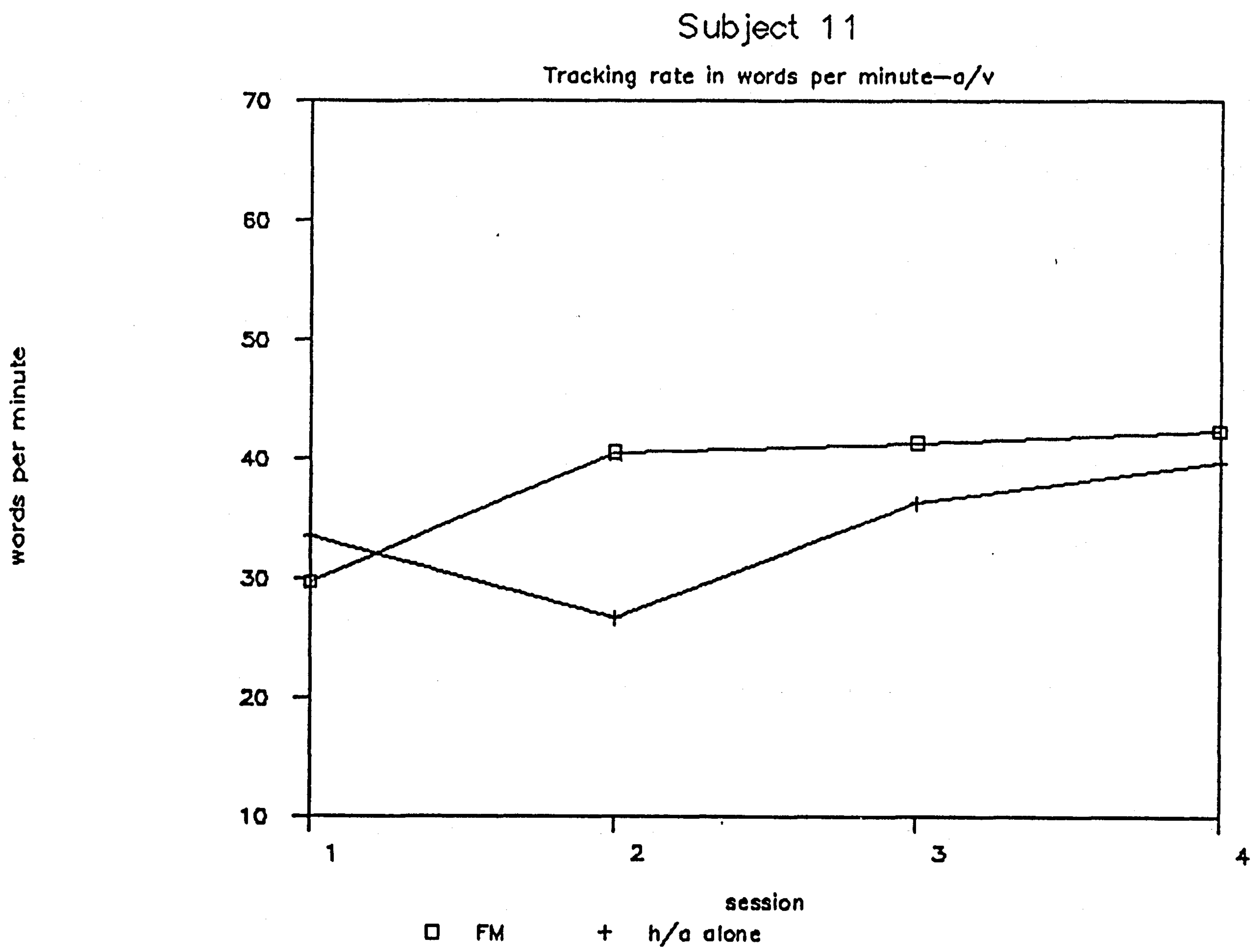

Subject 6
Tracking rate in words per minute
words per minute
70
60
50
40
30
20
10
1
2
3
4
session
FM
+ h/a alone


Subject 7
Tracking rate in words per minute
words per minute
70
60
50
40
30
20
10
1
2
3
4
session
FM
h/a alone

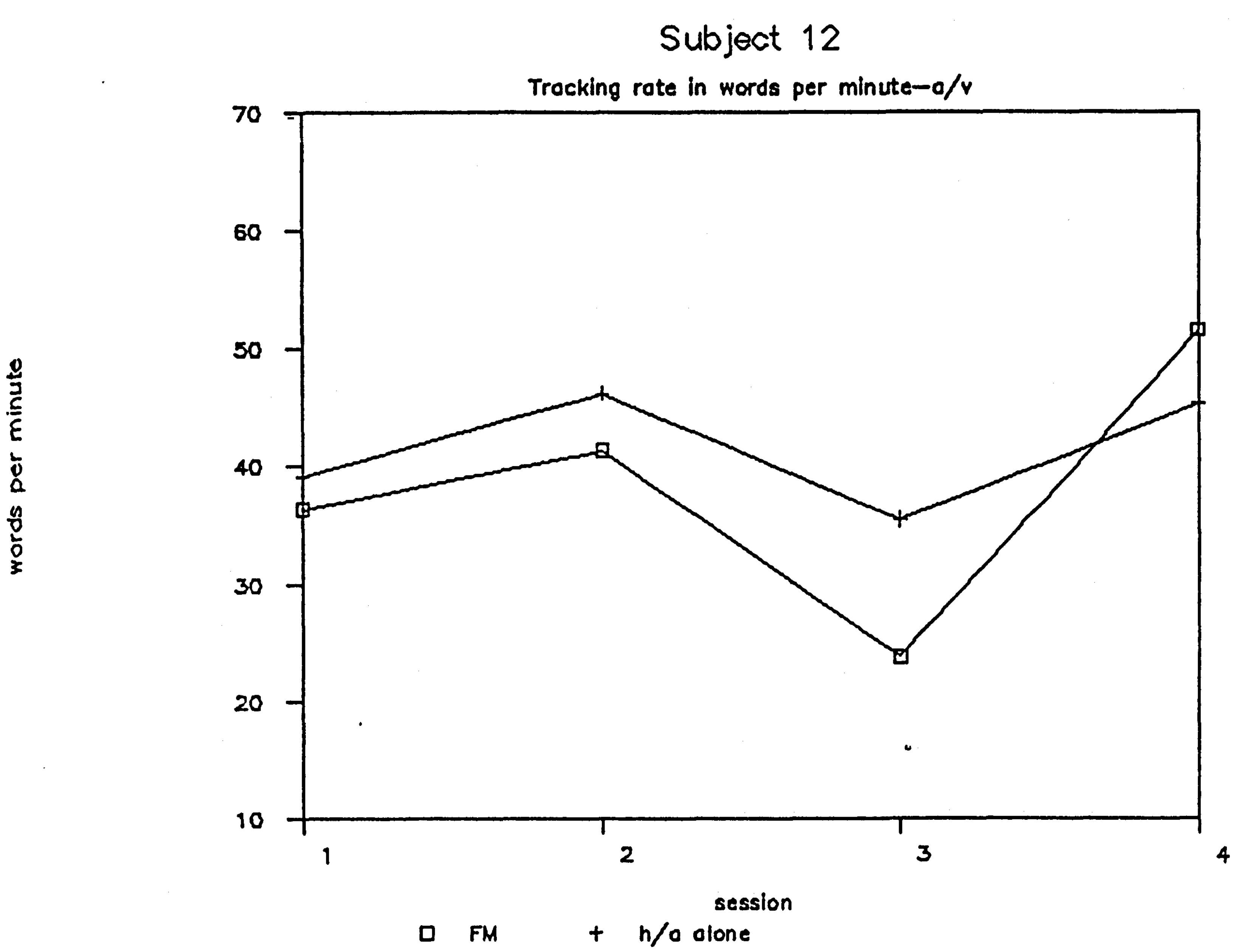

Subject 8
Tracking rate in words per minute
words per minute
70
60
50
40
30
20
10
1
2
3
4
session
FM
h/a alone


Subject 9
Tracking rate in words per minute
words per minute
70
60
50
40
30
20
10
1
2
3
4
session
FM
h/a alone


Subject 10
Tracking rate in words per minute—a/v
words per minute
70
60
50
40
30
20
10
1
2
3
4
session
FM
h/a alone



Subject 11
Tracking rate in words per minute—a/v
words per minute
70
60
50
40
30
20
10
1
2
3
4
session
FM
h/a alone



Subject 12
Tracking rate in words per minute—a/v
words per minute
70
60
50
40
30
20
10
1
2
3
4
session
FM
h/a alone

Therefore use of the FM significantly improved tracking rates for this group, with a mean advantage of 7 words per minute being found for the group as a whole. However, since subjects 10, 11 and 12 were tested under auditory-visual conditions it is of interest to separate their performances out in order to examine the influence of visual cues on FM advantage. This results in a mean FM advantage for auditory alone tracking of 8.9 words/minute, and of 1.2 words/minute for the subjects receiving both auditory and visual cues. It should be remembered, though, that subjects 10, 11 and 12 also had the worst hearing losses of the group.

2.3.2 : Comparison of improvements in tracking rates in the FM and hearing aid only listening conditions.

To examine the effects of both listening condition and session on tracking rates a 2x2 ANOVA was carried out on the raw data (see Appendix A). A significant main effect for both condition (F=21.44, df=1, p=.001, as expected from previous t-test results) and session (F=7.04, df=3, p=.001) was discovered. This means that there was a significant overall improvement in tracking rate over the 4 sessions (see Figure 2.1) No significant interaction between condition and session was revealed (F=2.016, p=.13).

However, another way of examining the data is to calculate how much improvement in tracking rate has occurred by comparing the first with the last session for both the FM and hearing aid alone listening conditions, that is to determine the overall improvement for each condition (see Table 2.4). Therefore a paired t-test (one tailed) was used to find whether there was any significant difference between the amount of tracking improvement seen in the hearing aid alone condition compared to the FM listening condition.

Table 2.4 : Improvement in tracking rates from the first to the fourth session in both FM and hearing aid conditions.

subject no.	improvement in tracking scores [rate in session 4 - rate in session 1]	
	h/a alone	FM
1	13.4	18.6
2	18.4	11.2
3	-1.2	5.8
4	7.4	10.6
5	7.2	12.8
6	0.2	19.2
7	-0.06	2.4
8	0.2	3.8
9	3.8	3.8
10	7.4	13
11	6.2	12.8
12	6.2	15.2
$\bar{x}$ =	5.72	10.73
SD =	5.82	5.46

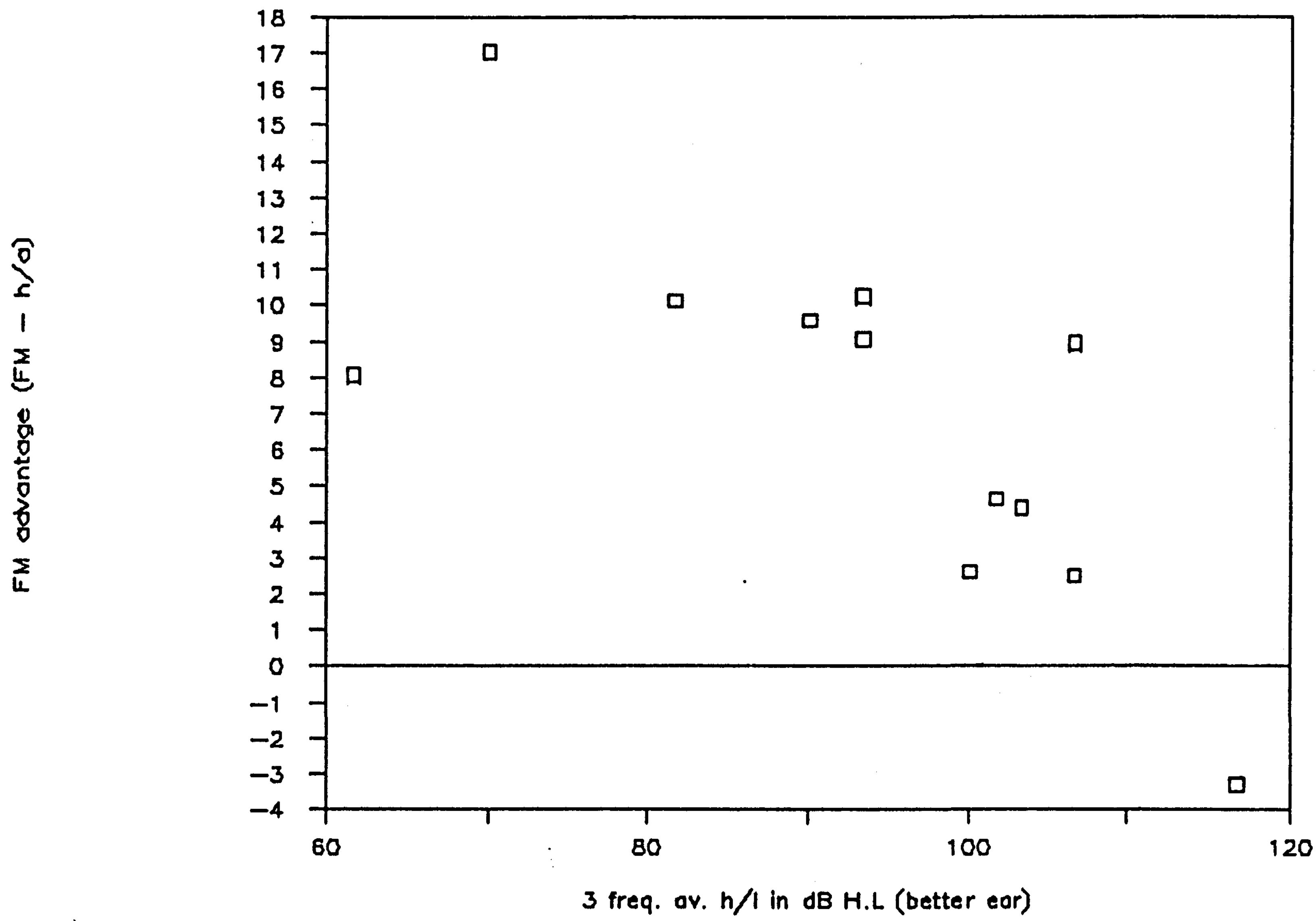
$t = 2.859$ (df=11)
significant at 0.01 level.

Thus tracking rate improvement for the FM condition was significantly greater than when listening through the hearing aid alone.

2.3.3 : Influence of degree of hearing loss on amount of FM advantage

Figure 2.2 is a scatter diagram showing the relationship between degree of hearing loss and FM advantage. This includes the subjects who were unable to cope with the difficulty of auditory alone tracking and who therefore were provided with visual cues. As these 3 listeners were amongst the deafest of the entire group, and since Figure 2.1 shows the auditory-visual condition was associated with a consistently small degree of FM advantage, their results can be seen to create the appearance of a correlation between hearing level and FM advantage.

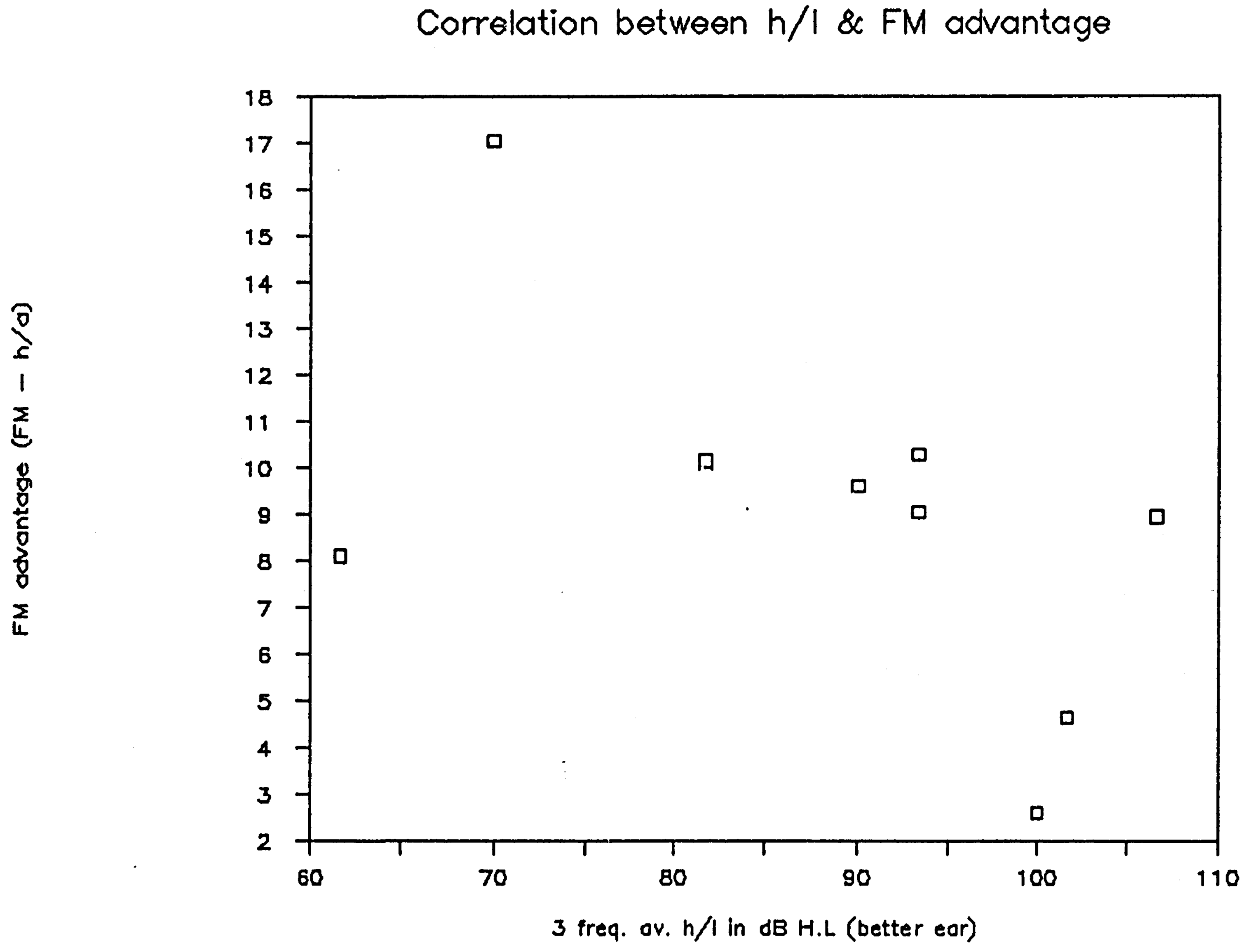
Figure 2.2 : All subjects Correlation between h/l & FM advantage



In fact the Pearson product moment correlation coefficient for this data was -.7295 which is significant at p < .01 level. Figure 2.3 shows the same data but with these 3 subjects excluded.

The corresponding correlation coefficient was -.535 which was not significant at the 0.05 level. Therefore when the results of those who were tested auditory-visually (and who were amongst those with the greatest hearing loss) are excluded, there does not appear to be a substantial relationship between degree of hearing loss and amount of FM advantage.

Figure 2.3: Subjects listening under auditory-visual conditions excluded



2.4 : DISCUSSION

The results of this experiment support the previous research findings of significant improvement in speech discrimination offered by FM systems (Ross & Giolas, 1971; Bankoski & Ross, 1984; Hawkins, 1984). It is reassuring to discover that the FM advantage shown in word level speech discrimination tests with mainly mild and moderate losses is carried over to continuous discourse in noisy classroom settings listened to by children even with severe and profound hearing losses. As explained in the rationale for this study, the present research more closely simulates the listening tasks that hearing impaired children are faced with daily in the classroom, and every effort was made to assess the FM unit in the conditions it was usually used.

The children varied considerably in the tracking gains they made with the FM compared to hearing aids alone. Table 2.3 shows improvements in the FM condition ranged from approximately 14% to 57% of the average rate in the hearing aid alone condition for those receiving auditory cues only. Even this lesser degree of improvement in following continuous discourse would be expected to have significant effect on the hearing impaired child's auditory comprehension and language learning in the classroom.

The paper by Hawkins (1984) shows that greater FM advantage is obtained from systems which are set so that the FM microphone only is active compared to having both the FM and environmental microphones working in combination. Despite the fact that the present study used only the latter combined setting, significant FM advantage was still demonstrated. This is an important finding in view of the observation that the combined setting is the more frequently used by hearing impaired children (see Chapter 5). It would be of interest to repeat this tracking procedure in order to measure how much extra improvement in tracking performance is offered by use of the FM alone setting.

The variability between subjects in amount of FM advantage that was observed in the present study cannot be readily explained on the basis of the information available. Degree of hearing loss was shown not to be significantly correlated with FM gain for the auditory listening condition, although there seemed to be a non-significant trend towards the more severely impaired users obtaining slightly less benefit (see Figure 2.3). It is probable that factors such as confidence, motivation, differences in materials used, auditory abilities and language competence also allowed some children to take greater advantage of the improved signal offered by the FM.

FM advantage was found to be considerably less for the 3 subjects who had visual cues available to them, and for subject 12 there was even an overall reduction in tracking rate in the FM listening condition. However, as mentioned, the meaning of these results are confounded by the fact that these children also had far worse hearing, on average, than the group who performed tracking through audition alone. It is therefore not clear whether this comparative reduction in FM gain is due to the severity of the hearing loss or the use of visual information, and it is possible that both factors may be making contributions. Ideally the study should be repeated using individuals with less severe losses and provided with visual cues in order to clarify the matter. For listeners with poor residual hearing, the visual reception of speech in an auditory-visual task is likely to dominate the receptive process. If this were to occur, then an improvement in the clarity of the auditory signal may have little or no effect on the overall level of perception. Nevertheless, the reality of classroom situations is that visual signals are not always available, or when they are, they may not always be under ideal conditions, so that audition must be relied upon at certain times. In any case, the visual component alone cannot provide an unambiguous channel for speech reception. In addition, the child is more likely to develop and use his auditory skills if he receives an optimal signal on a consistent basis. Therefore it is of greater interest to conduct auditory alone assessments as done in the present study.

The finding that tracking rate improved over the 4 sessions for both hearing aid and FM listening conditions is not surprising since the tracking procedure is, in itself, a training method for improving receptive speech skills (De Filippo & Scott, 1978; Danz & Binnie, 1983). The fact that there was significantly greater improvement in tracking rates for the FM listening condition than for listening through the hearing aid alone is, however, an interesting result. It suggests that either the listening skills of the subjects through their personal hearing aids was already near or quickly reached a ceiling level, or that the children in this study were not already well trained in making the most of the improved signal obtained through the FM, compared to their skills of listening through their hearing aids alone. Results of previous studies using tracking with hearing impaired subjects would suggest the latter explanation to be more likely as asymptotic performance is rarely reached in as short a period as four 5 minute sessions (De Filippo & Scott, 1978; Danz & Binnie, 1983). In either case the present study demonstrates that tracking of continuous discourse may well be a useful training tool in assisting hearing impaired children to receive the benefits of and to gain optimal advantage from the FM systems with which they have been provided.

CHAPTER 3

SUBJECTIVE PREFERENCES OF HEARING IMPAIRED CHILDREN FOR LISTENING THROUGH FM SYSTEMS USING A PAIRED COMPARISON PROCEDURE

3.1.: RATIONALE

The extent to which hearing impaired children will accept and use FM systems is expected to be partly determined by their perceptions of the improvements in speech intelligibility and sound quality that are offered. However, there has never been any research on this topic. This study thus aims to evaluate various features of FM units by attempting to gain access to subjective responses using a paired comparison procedure. Factors which might affect these responses will also be considered.

3.2 : METHOD

3.2.1 : Subjects

Over a two month period 21 children with varying degrees of sensori-neural hearing loss who attended a hearing centre for routine reassessment, acted as participants in this experiment. Only children over the age of 10 years were included due to the complexity of the task involved. Details of ages, 3 frequency average hearing loss, type of FM system and previous FM experience can be found in Table 3.1.

TABLE 3.1 : Age, 3 frequency average hearing losses, and previous FM experience of all subjects participating in the paired comparison study.

Subject no.	Type of FM	Age in years	3 frequency average loss (dB H.L) L ear	R ear	Previous FM experience (* denotes use of a different type of system from that evaluated)
1	Calaid	13	83.3	66.7	rejected *
2	Calaid	17	80	103.3	rejected *
3	Calaid	17	83.3	91.7	none
4	Calaid	15	85	85	successful user *
5	Calaid	17	86.67	-	user - ? success *
6	Calaid	17	-	88.3	user - ? success
7	Calaid	13	88.3	95	successful user *
8	Calaid	13	93.3	103.3	successful user
9	Calaid	14	-	96.7	rejected *
10	Calaid	12	-	100	successful user
11	Calaid	14	108.3	110	successful user
12	Sennheiser	11	56.7	83.3	successful user *
13	Sennheiser	11	76.7	75	none
14	Sennheiser	17	83.3	76.7	rejected *
15	Sennheiser	14	86.7	86.7	successful user
16	Sennheiser	15	86.7	86.7	successful user
17	Sennheiser	12	85	-	successful user *
18	Sennheiser	11	86.7	-	rejected
19	Sennheiser	18	96.7	100	none
20	Sennheiser	17	105	-	none
21	Sennheiser	14	105	108.3	successful user *

Fourteen subjects wore binaural hearing aids and seven were monaural aid users who had rejected wearing their second aid due to poorer hearing in this ear.

The success of FM use was decided on the basis of daily use of the system as established from questionnaire data obtained using the survey described in Chapter 5. Questionable success indicates that the system was only used intermittently.

3.2.2 : Equipment

The hearing aids : The children wore their own high-powered Phonak PPC-2 or PPCL aids, selected with the assistance of any necessary modifications, to provide the required real-ear frequency response specified by the Byrne and Dillon procedure (1986). Hearing aid volume was set to the child's usual listening level.

The FM systems : The two models of FM systems currently being fitted by NAL were evaluated. General details about the Calaid FM (4 channel) have been given in section 2.2.2. The Calaid FM has three different modes of operation : FM microphone only (FM only), voice operated switch (VOX), and a combined FM/environmental microphone switch (C). The voice operated switch has a turn on delay of 50msec and hang time of 1.5 to 2.0 secs. In addition, it has three different microphone options : an on-unit boom microphone (OU) which incorporates a noise cancellation system, an omnidirectional lapel microphone (L) and an omnidirectional head worn microphone (HW). The latter is preferable when using the VOX mode as it eliminates any drop in signal strength below the VOX turn on threshold as the wearer turns her head. The Calaid incorporates an AGC circuit to ensure consistency of signal strength and this has a threshold of 78 dB SPL at 1 kHz (lower for higher frequencies).

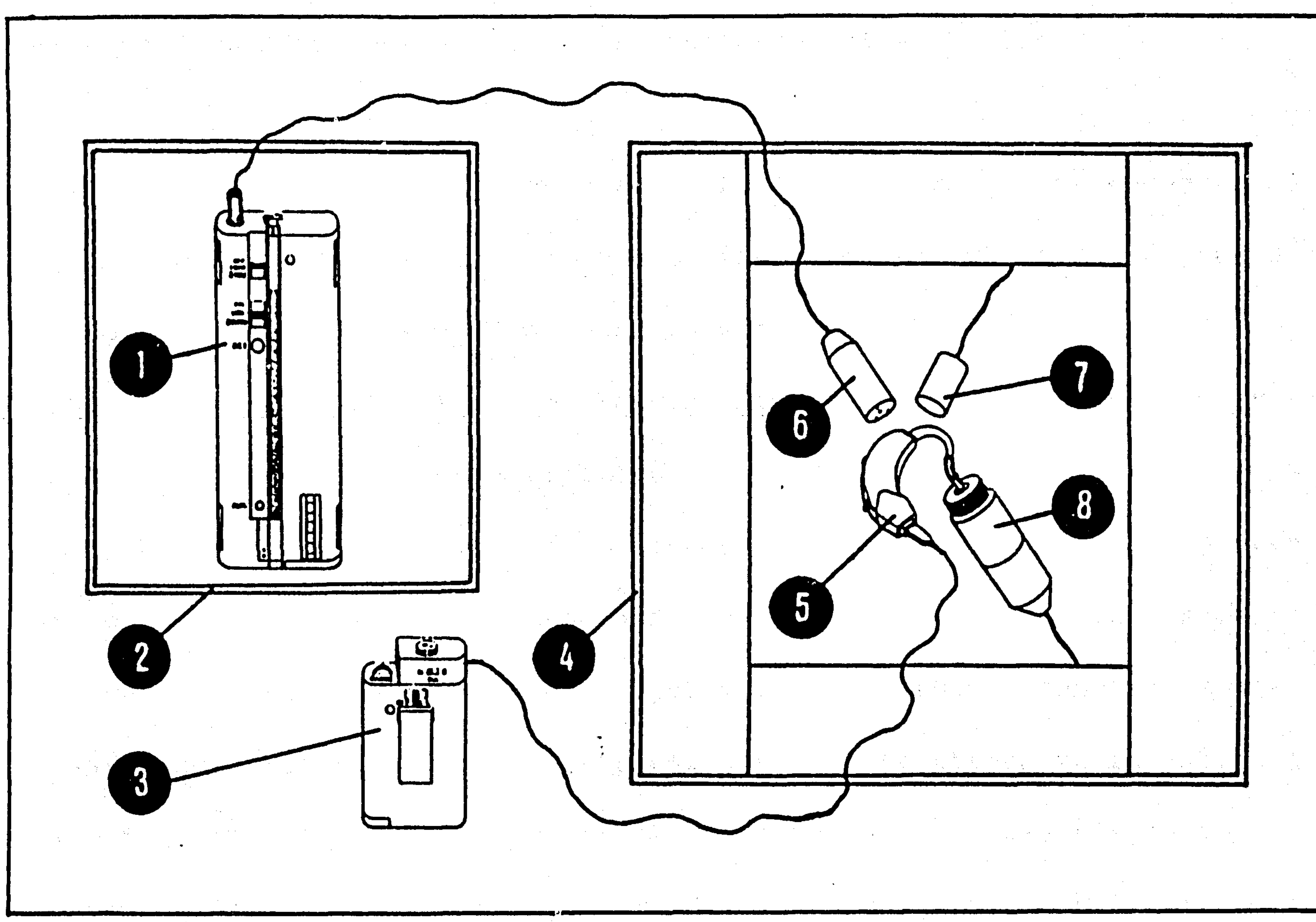
The Sennheiser FM system (1013 Mikroport) operates in the VHF range and its features include direct input coupling to the hearing aid, choice of combined FM/environmental microphone modes (C) or a signal operated switch (SOX), and a directional lapel microphone. The SOX turn on delay is 30msec and hang time 1 to 2 seconds. The Sennheiser does not have an active AGC circuit as some problems had been experienced with the functioning of this feature.

These various features of the particular FM systems employed were measured electroacoustically through the hearing aids used in the study and using the equipment and set up shown in Figure 3.1. Frequency response changes in hearing aid output when the FM was connected are shown in Table 3.2.

TABLE 3.2 : Frequency response alterations in hearing aid response caused by direct input connection to FM

Type of FM system	change in gain (dB) compared to hearing aid alone response				
	.25kHz	.5kHz	1kHz	2kHz	4kHz
Calaid FM	+5	+3	0	-3	-9
Sennheiser FM	0	0	0	-2	-4

Figure 3.1 : Test arrangement for the frequency response and volume control measurements of the FM systems



1) transmitter 2) acoustically isolated test box 3) receiver 4) test box (NAL sweep system - type 8500) 5) hearing aid with shoe 6) lapel microphone 7) test box microphone 8) 2cc coupler

Differences in output levels created by changing from one mode to another were measured. For the Calaid FM system, switching from FM alone or VOX mode to the combined FM/EM setting caused a 7 dB drop in output level transmitted through the FM system. Altering the Sennheiser 1013 system from triggered SOX to combined setting was found to cause a 6 dB increase in output level transmitted through the FM system.

The 3 microphone options on the Calaid were also compared on the transmitter used in the evaluation, and whilst the lapel and headworn microphones were no different, the on-unit boom microphone was found to be 2 to 4 dB less sensitive at frequencies below 2 kHz.

The volume control settings used were the same as those recommended when fitting the systems. This was the point at which a typical 85 dBSPL speech signal from the FM microphone was expected to provide the same level of output from the hearing aid as would a 70 dBSPL speech signal at the hearing aid microphone. This volume setting was marked on all the receivers. For the Sennheiser receivers, there were two markers, one for the SOX mode and one for the combined in order to compensate for the observed output variation when changing modes. However this was not done for the Calaids. In addition, to investigate acceptance of different volume settings markers were also placed on the volume control to indicate where +5 dB and -5 dB from this level could be adjusted. The margin for error in careful adjustment of the volume control wheel to these markers was found to be only + or - 1 dB.

These procedures meant that there was a drop of 7 dB in FM transmitted output when changing from FM only to combined mode on the Calaid. Thus the output received by the child when on C would have been less than that recommended, since the Calaid volume calibration and wheel marking was carried out on the louder "FM" setting. However this is partly compensated for in terms of the relative hearing aid microphone sensitivity on the combined setting as there is a damping effect of appproximately 4 dB on this sensitivity when the FM receiver is attached due to the increased load on the circuit. The result is that both the FM and the hearing aid microphone signals are attenuated to different degrees (the FM microphone by 3 dB more than the hearing aid microphone) when on the C mode, but for each signal path, both the signal and the noise are similarly affected so the S/N ratio is undisturbed. Another reason why this arrangement was accepted in the study was that questionnaire data (see Chapter 5) and clinical experience showed that this was the way the receivers were being worn by children, the volume settings reportedly remaining constant despite the mode selected.

The equipment used in the paired comparison procedure consisted of a TEAC A 360 stereo cassette deck connected to a Technics stereo integrated amplifier (SU-7300). A speech passage on the left channel was connected to a loudspeaker located at ear level directly in front of the subject at one metre from the ear. The speech babble on the right channel was fed to a second ear level speaker 2 metres behind the subject. The output levels of the cassette deck were adjusted so that a Bruel and Kjaer sound level meter (type 2206, with a 1" pressure microphone) placed at the ear's position resulted in a 70 dBSPL (Leq) speech signal and a 60 dBSPL (Leq) noise signal, thereby creating a +10 dB S/N ratio. These levels were chosen to represent typical classroom conditions if seated in an ideal listening position. The noise level measured at the FM microphone position, 15 cm from the speaker, was found to be 60 dBSPL also, whereas the speech signal at this position was 84 dBSPL.

The paired comparison listening conditions achieved by means of setting two receivers on different conditions and connecting both of these to a three position switching box. The two extreme switch positions (labelled 1 and 2) constituted the two receiver outputs and the middle switch acted as an open circuit position allowing the FM system to be disconnected without the damping effect on hearing aid output that is usually noted with the Calaid FM when the receiver is connected and the transmitter or receiver turned off. Thus the middle switch had the same effect as detaching the FM system entirely.

The output of the switching boxes lead to two audio contact shoes which provided direct input coupling to the hearing aids of the subject. Thus there were two switching boxes, one for each type of FM system. In addition, a third box allowed connection of two different microphones, a lapel and a headworn style, so that these could also be evaluated. To compare the on-unit boom microphone, the accessory microphone jack was pulled out of the transmitter, thereby activating the on-unit option. Measurement of FM output at the hearing aid was carried out and showed no effect to be caused by insertion of the switching boxes in the system.

3.2.3 : Materials and recording

A passage from a children's book, "Buttons - The Dog who was more than a Friend" was recorded by a female speaker in two segments of approximately 12 minutes each. The first session consisted of continuous reading of the text. The second segment of the text contained pauses of about 4 seconds at the end of each sentence. This was done for use in comparisons where different modes (FM only, C or SOX/VOX) were being contrasted so that the switching effect of the

SOX/VOX could be fully appreciated in view of the 1-2 second hang time before the hearing aid microphones resume their full sensitivity. The recording was made using a half inch pressure microphone (4155) attached to a Bruel and Kjaer sound level meter (module B2 7100, type 2231) which was in turn connected to the left channel of a TEAC A-360 stereo cassette deck. Male four speaker babble was simultaneously fed into the right channel from a TASCAM 58 8 channel tape deck. Speech noise was recorded onto the beginning of both tracks for use in calibration, and the Leq relationship between the calibration noise and the speech and babble signals noted.

3.2.4 : Instructions

The subjects were all asked for their help in a project to find out more about listening through FM systems. The specific instructions given to each subject were as follows :

"You are going to hear my voice reading a story about a little dog named Buttons. At the same time you will hear some noise in the background like voices all talking together. Try not to listen to the noise. I want you to just listen to the story and try to understand what it is about. While you are listening, I will give you this switch so that you can try two different ways of listening to the story. I will tell you which two switches to listen on each time - it can go on number 1 or number 2 or the middle like this. I want you to listen with it on one switch for a little while then try it on the other. Switch back and forth like this as much as you like until you can decide which position is the best for listening to the story - so that you can understand it the best. When you have decided, put up your hand and I will stop the tape for you to tell me. Then I will change what you can hear on each of the switches so it will be different things to listen to and we will do the same thing again. We will have lots of turns listening to different things so try to make up your mind as quickly as you can. Remember, just listen to the story and not the noise . Do you understand? Do you have any questions? Let's have a practice."

There was often a need for clarification at this point or after a practice session before some children fully understood what was required. In addition, the instructions to listen only to the story and to judge which of the pair allowed best understanding of this, were reiterated regularly throughout the testing session. During paired comparisons of different modes (FM only, C and SOX/VOX) the subjects were asked to listen to a whole sentence before switching to the other listening condition.

3.2.5 : Procedure

Each child evaluated either the Calaid or the Sennheiser unit. The decision as to which depended on what the child had been using. If the system they had been using was neither of these or they had never used an FM, they were randomly allocated to either group. The testing took place in a room with dimensions of 3.6 x 2.9 metres and 2.5 metres in height with an average reverberation time accross audiometric frequencies of 0.33 sec. After receiving instructions, the subjects were given a practice comparison to ensure they understood the task.

Three variable features of the Calaid were evaluated as to their effects on perceived speech intelligibility - FM/EM mode, microphone style and FM volume setting. There were only two features of the Sennheiser that could be similarly evaluated - mode and FM volume setting.

Each of these features had a number of possible options that could be selected on the transmitter or the receiver. These are shown in Table 3.3. Thus the number of comparisons depended upon the number of possible options that could be selected.

TABLE 3.3 : List of paired comparisons judged for intelligibility on each FM system.

Type of FM	mode comparisons (with lapel mic. & volume on recommended setting)	volume comparisons (with lapel mic.)	microphone comparisons (with combined mode & volume on recommended setting)
Calaid	FM only/VOX C/VOX C/FM only FM only/off VOX/off C/off	-5 dB/0 dB -5 dB/+5 dB +5 dB/0 dB (in combined mode)	HW/L HW/OU L/OU (in combined mode)
Sennheiser	C/SOX C/off SOX/off	-5 dB/0 dB -5 dB/+5 dB +5 dB/0 dB (in SOX mode)	- - -

All subjects in the Sennheiser group completed every evaluation as shown above, but only 6 of the subjects who listened to the Calaid completed the microphone evaluation and 9 subjects carried out the volume comparisons due to equipment breakdowns, lack of motivation or time constraints on the test session.

Each of the paired comparisons groups dealing with a certain feature was considered in a block. Within this block of paired comparisons, four repetitions of each condition were included to provide some guide as to the strength and reliability of the preference. These were counterbalanced for each repetition so that each receiver was set the same way only half the time to ensure no peculiarities of the particular units could significantly influence judgements or that response bias was occurring from subjects who might tend to always select the same switch position. All the trials within a block were presented in random order. The order of testing of the blocks of paired comparisons for each feature was also counterbalanced across subjects to control for practice and fatigue effects. After completion of each block of paired comparisons, a short rest was given.

For the majority of feature variations, the subjects were unable to see the settings on the receiver or transmitter or the changes that were made between each paired comparison, since the experimenter sat behind the subject with the receiver units out of his line of vision. In this way, any preconceptions caused by previous experience were not likely to affect judgements. The transmitter settings were not able to be seen either as the unit was not facing the subject, but when comparing the VOX setting on the Calaid FM, the switch for which is on the transmitter, with another mode that required the "FM" setting, also selected on the transmitter, the experimenter had to physically alter the switch position from VOX to FM in time with the switching of the subject.

Volume control settings were limited to three, 5 dB steps - 5 dB lower than the usual recommended setting, 5 dB above the usual setting, and usual setting itself, as it was felt these would represent significant variations in level that may be considered preferable to listeners. Whilst carrying out the volume comparisons, the FM systems were set on the most frequently used mode of operation according to the survey reported in Chapter 5 - on combined microphone switch for the Calaid FM and on SOX for the Sennheiser. Similarly, with each type of FM system, the commonly used lapel microphone was selected for both volume and mode evaluations.

Comparisons amongst the Calaid FM microphone styles were carried out live-voice in order to better gauge directional effects of the speaker's voice. Part of the same "Buttons" passage was read to the subject at an average 70 dBSPL, as monitored by a Bruel and Kjaer type 2206 sound level meter, positioned at the same distance from the speaker as the subject's ear. Instructions were to look down and not at the experimenter during this section of the test so that visual cues were not available. The experimenter wore the lapel and on-unit boom microphones at the usual recommended 15 cm from the mouth and the headworn set at 5cm distance, which was also considered a fairly typical arrangement. Microphone evaluations were conducted with the Calaid FM set on the combined mode and recommended volume setting, again to correspond with the way the system is most commonly used.

After the subject had signalled his decision made, the tape was stopped and his judgement recorded for each paired comparison. The experimenter then changed the settings ready for the next comparison and instructed as to which two of the three possible switch positions he was to listen to next, number one, two or the middle. Furthermore, at least once during the four repeats for every comparison, the listener was asked why he had judged his preferred choice to be better than its pair, and this reason was recorded. The entire testing session usually lasted about 30-45 minutes for the Sennheiser (24 comparisons), and around one hour for the Calaid FM evaluation (48 paired comparisons).

At a separate appointment, 11 of these subjects (numbers 3, 4, 6, 9, 10, 11, 12, 13, 15, 16, 21) were also tested using the adaptive speech test described in Chapter 4. These particular subjects were chosen simply on the basis of availability to do this further test. The additional test was carried out using the same systems as had been used for the paired comparison evaluation, set in the same way. Full details of this procedure can be found in section 4.3.

3.3 : RESULTS

3.3.1 : Overall preferences of listeners for each FM feature

The preferences of all subjects were analysed in two ways : in terms of the number of times each comparison condition was selected for all the trials and also by looking at the significant preferences of individual listeners. Tables 3.4 and 3.5 show the number of times each comparison condition was preferred for both the Calaid and the Sennheiser FM's. Chi-square tests were conducted on these frequencies and the results of this analysis can also be found in these tables.

Table 3.4 : Number of times each feature was preferred over all trials by all listeners and results of Chi-square tests on this data (df=1) - Calaid FM

Feature	comparison pair		Chi-square value	p
mode (n = 44 comparisons)	FM alone 22(6)	VOX 22(6)	0	.995
	VOX 13(8)	C 31(4)	7.36	.006 **
	C 32(4)	FM alone 12(6)	9.09	.0026**
	FM alone 15(11)	off 29(1)	4.45	.03 *
	VOX 15(10)	off 29(2)	4.45	.03 *
	C 22(9)	off 22(3)	0	.995
microphone (n = 24 comparisons)	HW 14(8)	L 10(0)	.667	.41
	HW 15(8)	OU 9(0)	1.5	.22
	L 12(5)	OU 12(3)	0	.995
volume (n = 36 comparisons)	-5dB 13(3)	0dB 23(5)	2.773	.09
	-5dB 16(2)	+5dB 20(6)	.444	.505
	+5dB 13(4)	0dB 23(4)	2.773	.09

* denotes significant difference, $p < .05$
** denotes significant difference, $p < .01$
Figures in brackets indicate the number of preferences indicated by experienced, successful users of the Calaid FM for each pair in each comparison.

Table 3.5 : Number of times each feature was preferred over all trials by all listeners and results of Chi-square tests on this data (df=1) - Sennheiser 1013 FM

Feature	comparison pair		chi-square value	p
Mode (n = 40 comparisons)	SOX 11(0)	C 29(8)	8.1	.004**
	C 16(4)	off 24(4)	1.6	.206
	SOX 8(0)	off 32(8)	14.4	.0001**
volume (n = 40 comparsions)	-5dB 9(2)	0 31(6)	12.1	.0005**
	-5dB 6(2)	+5dB 34(6)	19.6	.0000**
	0dB 11(2)	+5dB 29(6)	8.1	.004**

* denotes significant difference, $p < .05$
**denotes significant difference, $p < .01$
Figures in brackets indicate the number of preferences indicated by successful, experienced users of the Sennheiser 1013 FM for each pair in each comparison.

Figures 3.2 to 3.6 illustrate the percentage of times each condition was chosen for each feature in both the Calaid and Sennheiser evaluations.

Figure 3.2 : Percentage of times each mode was preferred for each paired comparison in the Calaid FM evaluation.

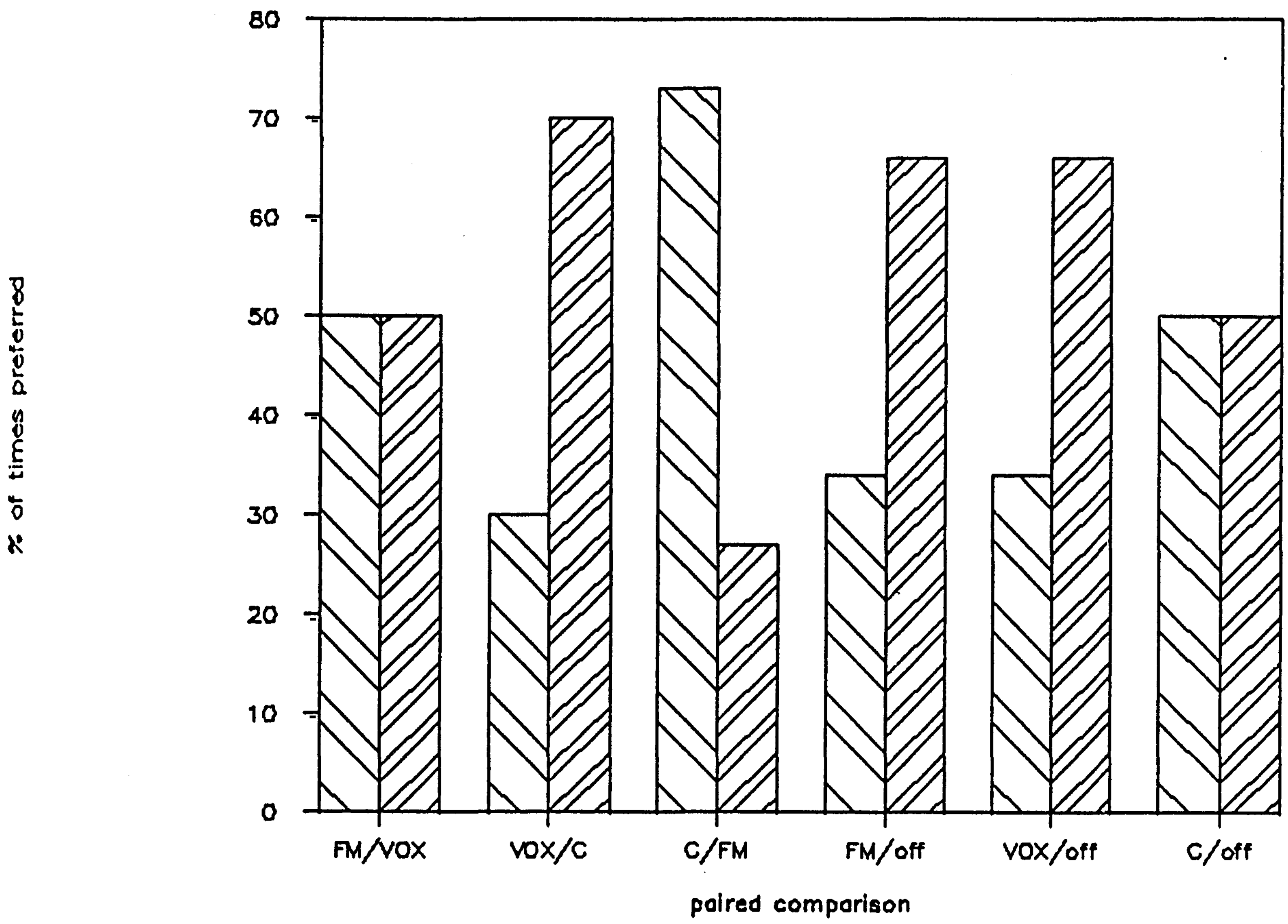


Figure 3.3: Percentage of times each microphone option was preferred for each paired comparison in the Calaid FM evaluation.

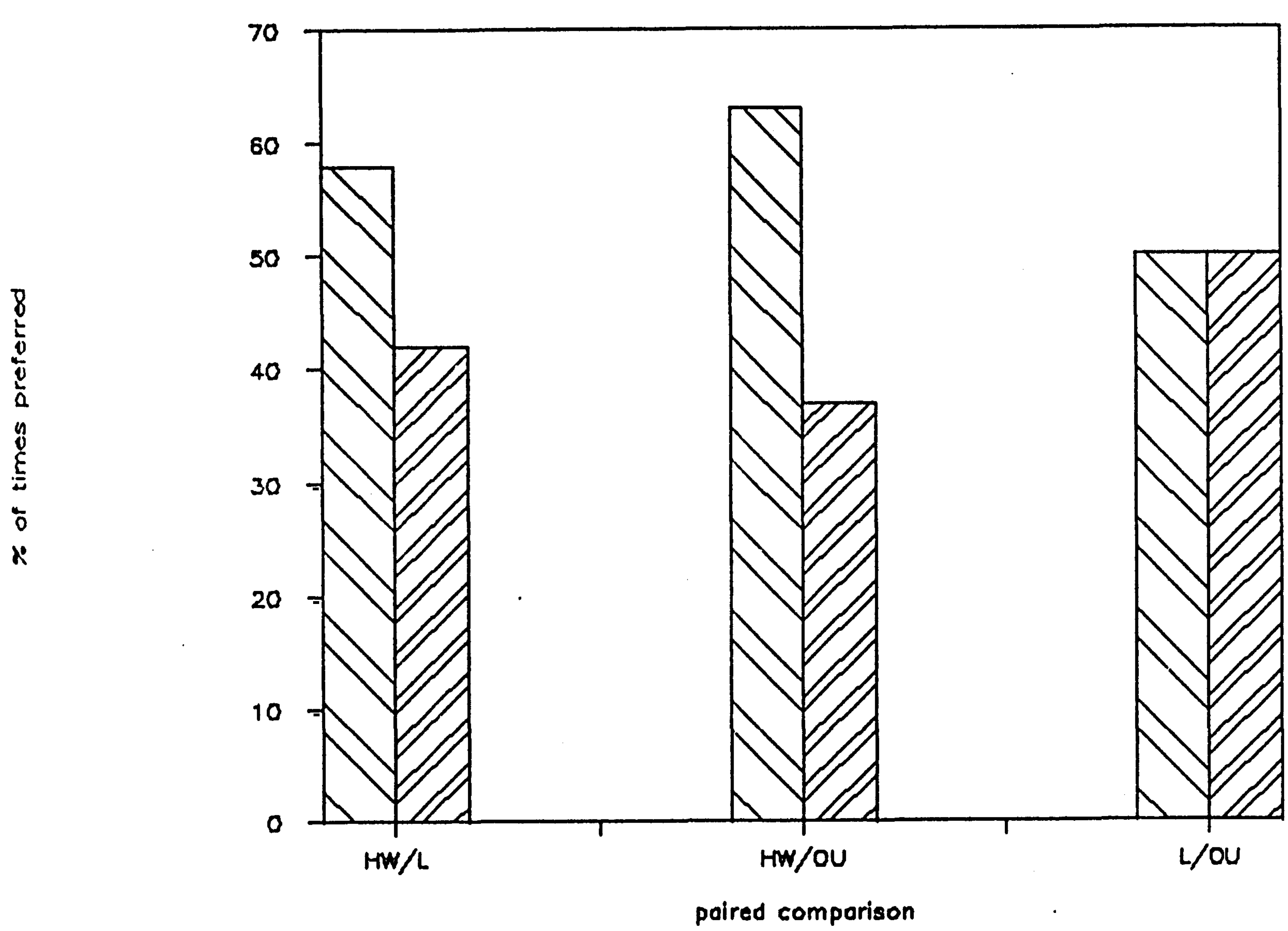


Figure 3.4 : Percentage of times each volume setting was preferred for each paired comparison in the Calaid FM evaluation.

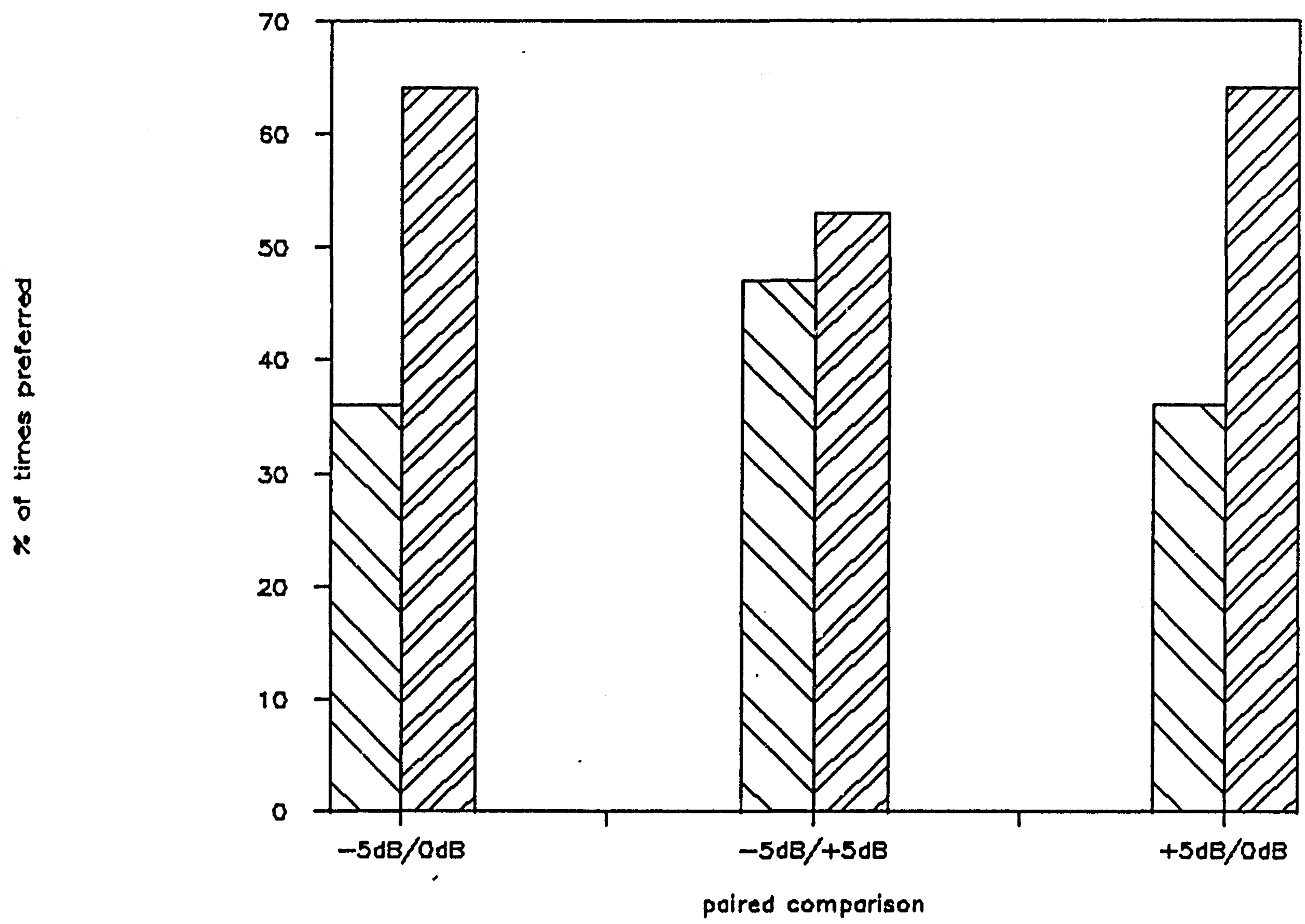


Figure 3.5 : Percentage of times each mode was preferred for each paired comparison in the Sennheiser FM evaluation.

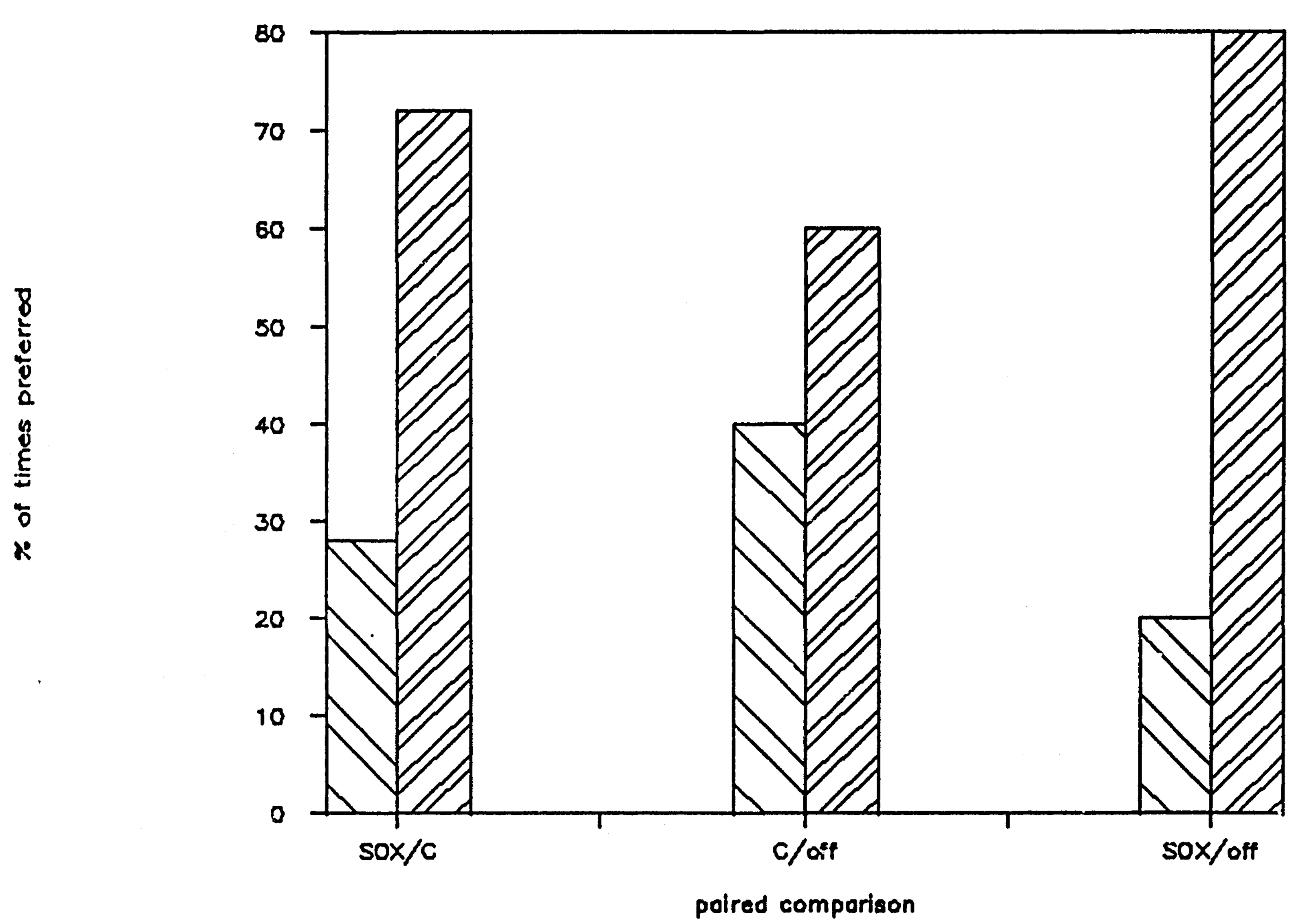
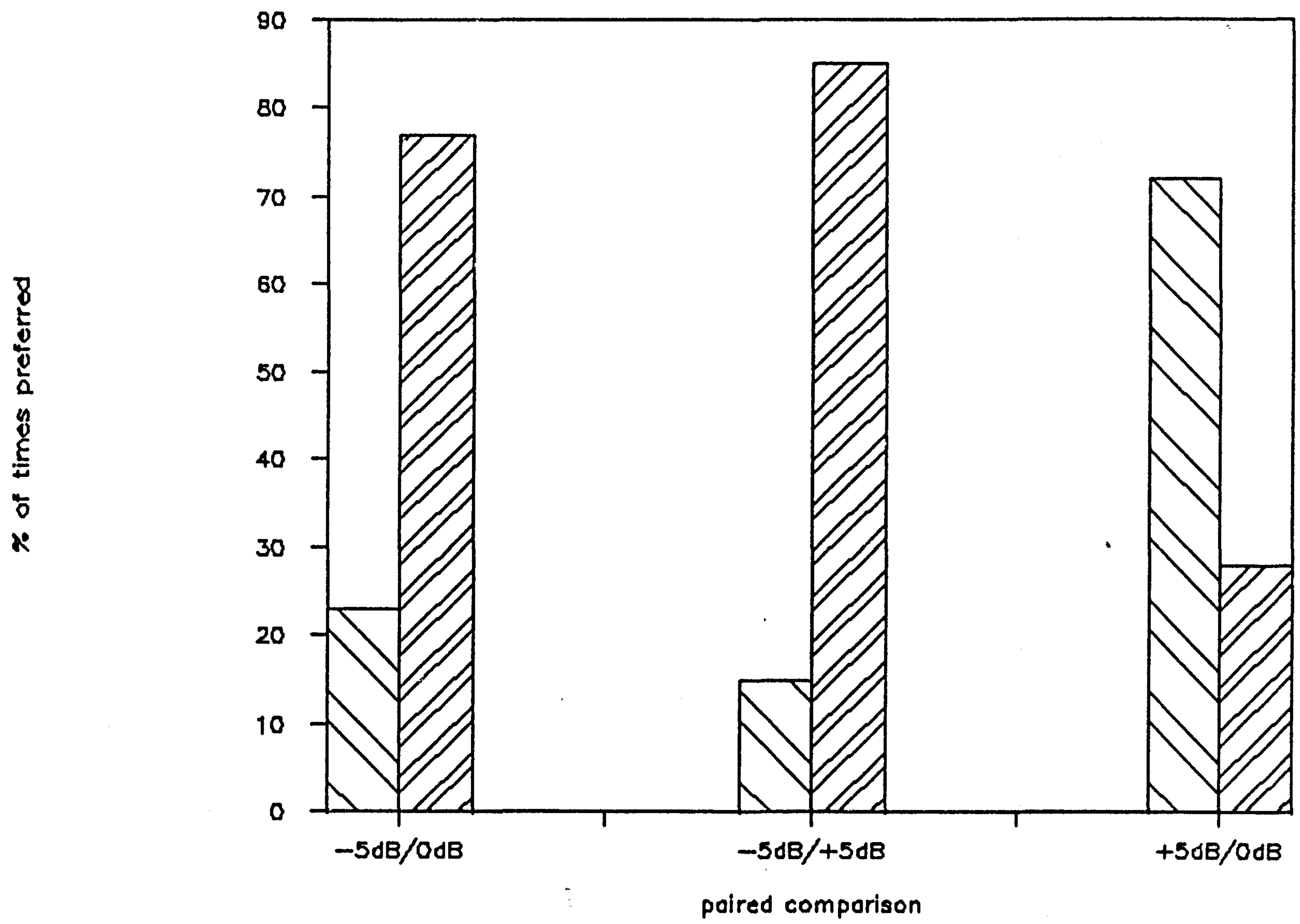


Figure 3.6 : Percentage of times each volume setting was preferred for each paired comparison in the Sennheiser FM evaluation.



Therefore, for the Calaid listener sample as a whole, results show C to be significantly preferred over VOX as well as FM alone, and the hearing aid alone to be preferred significantly more often than both FM and C. None of the volume or microphone options were chosen at above chance levels, although there was a trend (significant at the 10% level) for the recommended volume control setting to be chosen over either alternative. On the other hand, for the Sennheiser listeners, C was preferred significantly more often than SOX, hearing aid alone was preferred to SOX, and for the volume, in all cases the louder of the two settings in each pair was significantly preferred.

3.3.2 : Significant preferences of individual listeners for each FM feature

The figures in the following 2 tables, 3.6 and 3.7, describe the results of the second method of analysis. The probability of each listener's preferences being significantly above chance was calculated using the Binomial distribution (n = 4) for each set of 4 repeated trials of each paired comparison. The resultant criterion for a significant preference was thus 4 out of 4 choices for the same alternative.

Table 3.6: Number of listeners showing significant preferences for each comparison pair - Calaid FM

Feature	Comparison pairs and frequencies	
mode (n = 11 listeners)	FM - 0(0)	VOX - 0(0)
	VOX - 1(1)	FM - 5(0)
	C - 4(0)	FM - 0(0)
	FM - 2(2)	off - 5(0)
	VOX - 2(2)	off - 5(0)
	C - 1(1)	off - 1(0)
microphone (n = 6 listeners)	HW - 3(2)	L - 1(0)
	HW - 3(1)	OU - 2(0)
	L - 1(0)	OU - 1(0)
volume (n = 9 listeners)	-5dB - 1(0)	0dB - 3(0)
	-5dB - 2(0)	+5dB - 2(0)
	+5dB - 1(0)	0dB - 2(0)

Note : figures in brackets indicate the number of successful, experienced users who showed a significant preference in each paired comparison (a total of 3 successful users took part).

Table 3.7 : Number of listeners showing significant preferences for each comparison pair - Sennheiser 1013.

Feature	Comparisons pairs and frequencies	
mode (n = 10 listeners)	SOX - 1(0)	C - 6(2)
	C - 1(0)	off - 3(0)
	SOX - 1(0)	off - 6(2)
volume (n = 10 listeners)	-5dB - 0(0)	0dB - 4(1)
	-5dB - 0(0)	+5dB - 7(1)
	+5dB - 4(1)	0dB - 0(0)

Note : figures in brackets indicate the number of successful, experienced users of the Sennheiser 1013 who showed a significant preference in each paired comparison (a total of 2 successful users took part).

These results show that there was not always consensus amongst individual listeners as to what they preferred, although there was greater agreement amongst the listeners to the Sennheiser unit.

3.3.3 : Effects of previous experience using FM systems on listener preferences

In addition, the effects of listener experience in using FM's was examined. The number of preferences shown for each alternative in each pair (that is, the data from Table 3.4) was categorised according to the type of previous FM experience the listener had. Using the Binomial distribution, the following groups were found to show overall preferences that were significantly above chance ($p < .05$), as summarised in Table 3.8 :

Table 3.8 : Comparisons which were preferred significantly above chance levels for subjects grouped according to previous FM listening experience (- indicates there was no significant preference shown)

Calaids : mode :	Comparison pairs					
	FM/VOX	VOX/C	C/FM	FM/off	VOX/off	C/off
successful, experienced users of the Calaid FM (n = 3)	-	-	-	FM	VOX	C
experienced users of the Calaid FM with questionable success (n = 1)	-	C	C	off	off	off
successful users of another type of FM (n = 3)	-	C	C	off	off	off
previous users who have rejected FM use (n = 3)	-	C		off	off	-
non-users (n = 1)	-	C	C	off	-	-

microphone :	HW/L	HW/OU	L/OU
successful, experienced users of the Calaid FM (n = 2)	HW	HW	-
successful users of another type of FM (n = 2)	L	-	-
previous users who have rejected FM use (n = 1)	-	OU	OU
non-users (n = 1)	-	-	-

volume :	-5dB/0dB	-5dB/+5dB	+5dB/0dB
successful, experienced users of the Calaid FM (n = 2)	-	-	-
experienced users of the Calaid FM with questionable success (n = 1)	-5dB	-5dB	0dB
successful users of another type of FM (n = 3)	0dB	-	0dB
previous users who have rejected FM use (n = 2)	-	-	-
non-users (n = 1)	-	-	-

Sennheiser 1013 : mode	SOX/C	C/off	SOX/off
successful, experienced users of the Sennheiser FM (n = 2)	C	-	off
successful users of another type of FM (n = 3)	-	off	off
previous users who have rejected FM use (n = 2)	-	-	off
non-users (n = 3)	-	-	-
volume:	-5dB/0dB	-5dB/+5dB	+5dB/0dB
successful, experienced users of the Sennheiser FM (n = 2)	-	-	-
successful users of another type of FM (n = 3)	0dB	-	+5dB
previous users who have rejected FM use (n = 2)	-	+5dB	-
non-users (n = 3)	0dB	+5dB	+5dB

It is apparent from this analysis of the data that experienced successful users of the Calaid FM showed preferences for mode of operation that were different from those chosen as preferable by the other listeners. This trend was not apparent with the experienced successful users of the Sennheiser.

3.3.4 : Relationship between degree of hearing loss and preferred listening conditions

The overall results were also analysed to examine the effect degree of hearing loss may have on listener preferences for the mode used. These can be found in Appendix B. The Calaid results were confounded by the fact that 2 of the 4 profound listeners were also successful experienced listeners of this same device and therefore showed opposite preferences from other listeners for mode of operation. Once this is taken into account, no clear patterns emerge according to degree of hearing loss at least for this small group of listeners.

3.3.5 : Relationship between degree of FM advantage and preferred listening conditions.

Eleven of the subjects who carried out paired comparison judgements were also tested using the adaptive speech test described in Chapter 4. This was done to ensure that FM advantage was being obtained in terms of improved speech intelligibility for at least some of these listeners. Table 3.9 shows the preferred mode and the degree of FM advantage for each subject that participated in both studies.

These results show that there was very little complete agreement between paired comparison judgements and the measure of FM advantage that was used. Significant preferences and significant advantages were only shown for two comparisons for two listeners in each of the FM listening groups. On the other hand, significant preferences for the alternative mode to that shown to provide advantage were more common (6 times in each FM listening group). Another common situation was for no significant preference to be shown in the paired comparison procedure, and yet for significant advantage to be indicated (8 cases in the Calaid listening group, 3 cases in the Sennheiser group).

Table 3.9 : Individual preferences for mode settings and the corresponding measure of FM advantage for each listener in each listening condition

Subject no.	mode comparison	paired comparison result	difference in speech in noise thresholds between the 2 listening conditions
Calaid FM listeners :			
1	C vs FM	no significant preference	FM has 11.6 dB advantage *
	FM vs h/a alone	no significant preference	FM has 26.7 dB advantage *
	C vs h/a alone	no significant preference	C has 15.1 dB advantage *
2	C vs FM	C significantly preferred	FM has 13.4 dB advantage *
	FM vs h/a alone	h/a alone significantly preferred	FM has 25.2 dB advantage *
	C vs h/a alone	no significant preference	C has 11.8 dB advantage *
6	C vs FM	C significantly preferred	FM has 18.2 dB advantage *
	FM vs h/a alone	h/a alone significantly preferred	FM has 32.3 dB advantage *
	C vs h/a alone	h/a alone significantly preferred	C has 14.2 dB advantage *
7	C vs FM	no significant preference	no significant advantage
	FM vs h/a alone	no significant preference	FM has 17.5 dB advantage *
	C vs h/a alone	C significantly preferred	C has 12.9 dB advantage *
8	C vs FM	no significant preference	FM has 10.4 dB advantage *
	FM vs h/a alone	FM significantly preferred	FM has 23 dB advantage *
	C vs h/a alone	no significant preference	C has 12.6 dB advantage *
11	C vs FM	no significant preference	FM has 13.7 dB advantage *
	FM vs h/a alone	h/a alone significantly preferred	FM has 10.4 dB advantage *
	C vs h/a alone	no significant preference	h/a alone has 3.4 dB advantage *

Sennheiser listeners :			
12	SOX vs C	no significant preference	no significant advantage
	C vs h/a alone	h/a alone significantly preferred	C has 17.9 dB advantage *
	SOX vs h/a alone	h/a alone significantly preferred	SOX has 18.4 dB advantage *
13	SOX vs C	C significantly preferred	SOX has 5.8 dB advantage *
	C vs h/a alone	C significantly preferred	C has 3.2 dB advantage *
	SOX vs h/a alone	h/a alone significantly preferred	SOX has 9 dB advantage *
15	SOX vs C	C significantly preferred	no significant advantage
	C vs h/a alone	no significant preference	C has 12.2 dB advantage *
	SOX vs h/a alone	h/a alone significantly preferred	SOX has 14.6 dB advantage *
16	SOX vs C	C significantly preferred	C has 7.8 dB advantage *
	C vs h/a alone	no significant preference	C has 6.7 dB advantage *
	SOX vs h/a alone	h/a alone significantly preferred	no significant advantage
17	SOX vs C	C significantly preferred	no significant advantage
	C vs h/a alone	h/a alone significantly preferred	C has 6.0 dB advantage *
	SOX vs h/a alone	no significant preference	SOX has 6 dB advantage *

(* denotes significant degree of FM advantage as indicated by t-test, $p<0.05$ - see Section 4.3.2)

3.4 : DISCUSSION

3.4.1 : Mode preferences

The use of the paired comparison procedure to obtain information about subjective judgements of hearing impaired children in relation to FM systems, has provided a unique opportunity to gain insight into the interaction between individual and aid which would seem to have important clinical ramifications. Many clinicians are aware that children often do not respond to the benefits of FM equipment as well as would be expected from theoretical consideration of the advantages, as evidenced by their limited use of the unit. Previously this may have been put down purely to reluctance to accept the need to use further devices which may be bulky, intrusive and obvious to others (see Chapter 5). However, this study shows that children do not always prefer to listen to the signal which offers the most intelligible speech, and therefore that factors other than just reaction against the physical presence of extra equipment may be involved in determining at least initial acceptance of FM systems.

Tables 3.4 and 3.5 and Figures 3.2 to 3.6 show that overall the two groups of listeners indicated significant preferences against listening through any FM mode where the hearing aid microphone was deactivated (either FM alone, VOX or SOX), for both of the FM systems evaluated. In other words, depending on what it was compared with, the combined or hearing aid alone conditions were preferred. This was despite the fact that at least all the 11 subjects who were tested for FM advantage using the adaptive speech test procedure described in Chapter 4, obtained a significant S/N advantage in the FM alone and SOX settings compared to the hearing aid alone. Presumably the VOX setting on the Calaid would have shown the same advantage as FM alone as well, had it been measured in the same way. For the C setting compared to FM or SOX (with the exception of subject number 16) all listeners showed either a significant S/N advantage on the FM only or SOX setting (6 subjects) or at least no difference in performance between the C and FM/SOX conditions. However, overall subjective preferences significantly favoured the C setting regardless of these speech test results. These latter preferences occurred even with the Calaid FM where 7 dB lower output from the FM system was being received on the C setting compared to what was available on the FM alone or VOX switches (see section 3.2.2).

When the C setting is compared to the hearing aid alone, overall results showed no significant difference between preference frequencies for each alternative. Again the Calaid listeners would have obtained a lower level of output on the C setting than with the hearing aid alone so this may well have caused fewer preferences for the combined setting to be shown due to inadequate sensation level being available. On the other hand, of those 11 subjects also assessed with the adaptive speech test, 10 showed significant S/N ratio advantage from the FM on this setting. However, the degree of this FM advantage found was unexpectedly large as will be explained in section 4.4.

Thus, from these overall results, many preferences for FM mode or hearing aid alone do not correspond with the settings offering significant FM advantage. There are several possiblities that could be put forward in attempt to explain this apparent paradox.

Firstly the children may not have been judging the acceptability/intelligibility of the speech signal itself, but may rather have attended to the background noise as well or exclusively in making their decisions. It is conceivable this could have occurred with a few individuals, especially those who were younger and those with poorer language who may have misunderstood the instruction. However, the instructions to listen to the story only, were repeated with each child several times throughout the test, and it seems unlikely that the majority of subjects misinterpreted or were unable to follow these directions. Also, when asked why they had judged a particular mode as better, many replied that the preferred option was clearer, or "I could hear the story better", which would not suggest they were attending to the background noise.

Alternatively the listening task which was chosen in the test procedure may not have been of sufficient difficulty to allow the subjects to adequately discriminate between the FM and hearing aid listening conditions. As previous research has indicated, degree of FM advantage increases as the S/N ratio becomes less favourable (Hawkins, 1984). The +10 dB S/N ratio employed was chosen to represent a fairly typical classroom situation, although some research into classroom conditions has suggested poorer S/N ratios than this often exist (Sanders, 1965; Bess & McConnell, 1981; Denholme, 1983, cited in Nolan & Tucker, 1986 - see Table 1.4). As explained in section 1.2.2, however, the way in which speech and noise must necessarily be measured in classrooms may act to produce less favourable ratios than actually exist. Nevertheless, the results of Hawkins (1984) indicate that even at S/N ratios as good as +15 dB, improvement in speech discrimination scores occurred in both combined and FM alone conditions, so in the present study definite FM advantage should have been demonstrated. Also, the 0.33 sec reverberation times for the room in which testing took place were much lower than is usually observed in average classrooms (see Table 1.5). This would have also lessened the advantage of the FM in this study. Again, however, reverberation times as short as 0.4 sec have been shown to cause deterioration in speech discrimination scores (Finitzo-Hieber & Tilman, 1978) compared to non-reverberant conditions. Thus, this explanation also seems poorly supported by the available evidence.

The final and most plausible explanation offered is that the specific listeners used in the study may not have preferred the FM listening conditions to their hearing aids alone simply because they were often not used to, or at least less used to, FM processed signals (especially through the particular FM unit they were evaluating at the time). Certainly all of these children had spent the vast majority of their lives using only the information available to them through their hearing aids alone. Indeed, they would have learnt their auditory skills and auditory comprehension of language in this fashion. The introduction of an FM aid should ideally create an improvement in the amount of speech imformation available, but it nevertheless constitutes a change in the signal received which may necessitate some relearning. Not only do they receive less background noise, but they may also need to become accustomed to the effect of their hearing aid microphones being turned off and on without their control, the consistent speech levels caused by AGC circuits and constant microphone distance from the speaker, as well as slight differences in frequency response occurring through the FM relative to their own aid. The comparatively greater preference shown for the C setting on both FM aids may thus be due to their hearing aid amplified sound being still available to them on this setting. These theories are reinforced by the observation that pre-school and infants children, who are relatively new to amplified sound and still learning to use their auditory potential, are less likely to reject FM use compared to primary and high school students who have been using their hearing aids for a longer time (see Chapter 5). It is possible that the child who is so used to and depends upon a signal with particular properties will not judge any change to this signal as offering greater speech intelligibility, at least initially. This is not a reaction that is exclusive to FM aids as children are often seen in the clinic who resist any change in their hearing aid characteristics.

These speculations are supported by the data collected in this study. Tables 3.6 and 3.7 show that whilst there is reasonable consensus between the judgements of most individual listeners who show significant preferences for a particular mode, those individuals which differ from the norm, at least in the Calaid group, are without exception, those who have had considerable regular experience and success with the particular FM being evaluated. These individuals as a group have significantly preferred any FM condition to listening through their hearing aids alone, directly the opposite to the preferences of the rest of the sample. The fact that, for the Sennheiser group, there was no such trend for experienced, successful users to prefer listening through the

FM, weakens the argument somewhat, and it is difficult to understand why they should differ from the Calaid group.

It may be suggested that the experienced, successful users have become that because there was some interaction between them and the FM units that caused them to prefer the FM right from the start, rather than being something that developed with time and experience. There is not sufficient evidence present to be very sure which is the case, but the fact that Table 3.6 reveals there to be no other individuals amongst the 11 tested with this unit who show an initial positive reaction to the FM signal without having regularly used it, suggests that the positive response is a function of experience.

In any case, the most obvious solution to the problems of these negative subjective reactions of some children at least to some FM aids, is to provide some training programme for all children newly fitted with FM systems that will allow them to both become accustomed to the alteration in their amplification characteristics and auditory potential, and to appreciate the advantage the FM units are capable of providing, thereby developing their confidence in the system.

Another interesting finding with regard to FM mode preferences is that for the Calaid system, the VOX setting did not seem to be preferred any less often than did the FM alone setting. However, Chapter 5 shows that the "FM" mode is more often used than the VOX setting, perhaps due to reasons of teacher microphone preferences and the location of the switches for each as is discussed (section 5.4). The present study suggests that there is no negative subjective response to the on/off switching of the hearing aid microphones when on VOX, so, accepting the added advantages that the VOX offers, namely the ability to hear other children and to monitor their own voice when the teacher is not speaking, greater effort should be made to encourage regular use of this facility by children and teachers.

3.4.2 : Microphone style preferences

The study shows that the Calaid FM listeners had no significant preferences overall for any particular microphone style (Table 3.4). Analysis of the preferences of each individual listener (Table 3.6) reveals that of those listeners who had a strong preference, slightly more desired the headworn option. Therefore these results do not allow us to conclude that any of these microphones should be used as standard on the basis of subjective preference. However, the slightly more frequent choice of the headworn style by some individuals and the added benefits of such microphones to maintain constant distance from the lips despite head movement (thereby allowing consistent operation of the VOX mechanism) indicate that such headworn styles should be available and their use encouraged.

3.4.3 : Volume preferences

The results for these judgements differed depending on which FM system is considered. Overall judgements for the Calaid showed no significant preferences for any of the comparison settings, although there was a slight trend towards the recommended volume seting being preferred (p=.09) to either of the +5 dB or -5 dB alternatives. As shown by Table

3.6, though, some individuals significantly preferred the volume to be 5 dB louder and others for it to be 5 dB softer. Overall these subjective judgements suggest that the recommended volume setting is fairly appropriate, at least on the C setting where it was evaluated. However, as mentioned earlier, the C setting drops the FM output from the hearing aid by 7 dB so that the "recommended" volume creates a signal that is actually less by this amount than what was intended. Therefore, the level of an 85 dB SPL signal at the FM microphone results in an output which is 7 dB less in the ear than would be a 70 dB SPL signal at the hearing aid microphone when not connected to an FM system. Furthermore, since the hearing aid microphone itself is attenuated by about 4 dB from its usual sensitivity when on the C setting, this means that, for the test conditions chosen, the input from this source would have been louder by 3 dB relative to the FM signal, and the overall sensation level achieved less than through the hearing aid alone. Nevertheless, these listeners do not consistently prefer a volume setting which results in a louder output to compensate for this, an important finding since most wearers of the Calaid FM use the system on C with the volume on this recommended setting (see Chapter 5).

On the other hand, the Sennheiser listeners, in general, did desire a higher volume setting and this was a highly significant finding. In all comparisons the louder of the 2 setting always tended to be preferred. This suggests that the recommended volume setting, at least on the SOX setting and presumably also on the C setting , resulted in a loudness level less than that preferred by the listeners in this study. This may have contributed to some extent to the number of preferences against listening through the FM and for listening through the hearing aid alone that were shown. Such findings are difficult to explain in view of the carefully measured and selected volume control settings that were used to correspond to what would normally be a comfortable listening level for an average speech signal on the aid itself. Apparently there seems to be some additional effect on the signal which is not being compensated for using this volume setting procedure. This is a problem that is in need of further investigation with this system. Nevertheless results from the survey described in Chapter 5 indicate that in classroom situations children report that they more often use the recommended volume control setting that any other.

3.4.4 : Concluding remarks

The measurement of preferences of hearing impaired children for listening through FM systems has, in this way, provided access to subjective responses to FM processed signals which has not been available previously. The discovery of such information will allow audiologists and educators to better comprehend the experiences of hearing impaired children in relation to FM systems and therefore to provide services more appropriate to their needs.