M. Vingerling

The influence of prosodic cues on the perception of speech by normally hearing and hearing-impaired listeners: an exploratory study.

The influence of prosodic cues on the perception of speech by normally hearing and hearing-impaired listeners: an exploratory study

De invloed van prosodische factoren op de perceptie van spraak door normaalhorende en slechthorende luisteraars: een verkennend onderzoek

(met een samenvatting in het Nederlands)

Proefschrift

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Marianne Vingerling
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Promotor: Prof. Dr. A. Cohen

Co-promotor: Dr. M.P.R. van den Broecke

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To Ton,
on the occasion of the 25th dissertation
written under his supervision

To Tom,
on the occasion of the 25th dissertation
written under his supervision

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Curriculum vitae

Marianne Vingerling was born in Katwijk aan Zee on 2 September 1953. After obtaining her "Gymnasium α" certificate in 1971, she started studying English language and literature at the University of Utrecht in 1972. She received her "kandidaats" diploma in 1975 and graduated in 1978 with minors in phonetics and speech disorders. From 1 April 1979 till 1 January 1983 she carried out the present investigation at the Institute of Phonetics of Utrecht University. As she was employed on a part-time basis, she was teaching English at various schools for tertiary education at the same time. Since 1 September 1982 she has been a teacher of English at the "HEAO-school" in Sittard, from 1984 in a tenured position.

Chapter I

Introduction

1.1. Introduction

"Ours is not the silence that soothes the weary senses.
It is an inhuman silence which severs and estranges.
It is a silence which isolates, cruelly and completely.
Hearing is the deepest, most humanizing, philosophical sense man possesses."

The above quote from Keller (1979) describes the isolation of those who are unable to participate in the communication process due to a hearing impairment. The ability to communicate person-to-person is usually taken for granted by those participating in the everyday communication process. For human beings, speech is the principal means of communication and as such has an important social function. Consequently, if forced to choose between being either blind or deaf, many people would probably "prefer" the former to the latter. Generally, being blind does not prevent people from getting along with their fellow human beings whereas deaf people - deprived of their primary means of communication - tend to feel isolated, cut off from society. Apart from deafness, inability to communicate by means of speech can be due to various other causes. Since the process of speech communication is generally considered to have three different aspects, viz. production, transmission and perception, the cause may be related to any of the three aspects mentioned. In this investigation we will concentrate on perception. Difficulties experienced in perceiving speech may be due to external factors such as noise coming from various sources e.g. traffic, industry etc. but also other people's voices. The cause of difficulties may also be found among the participants in the process e.g. - as far as perception is concerned - reduced ability to perceive speech due to a hearing impairment. This example enables us to come straight to what our investigation is mainly concerned with, viz. the hearing-impaired individual and his/her difficulty in perceiving everyday speech.

1.2. Different approaches to hearing

The issue of hearing has been approached from various angles. Before enlarging on our own approach, we shall discuss two other ways of approaching the hearing problem, viz. the traditional and the ecological approach. Traditional approaches to hearing are based on acoustics and physiology and have led to studying the capacities of the auditory system and - as far as impaired hearing is concerned - to finding adequate ways of assessing quantitatively the impairment of a person's hearing ability. Approaching hearing from an ecological point of view means trying to relate the process of hearing to audible features and characteristics of the real day-to-day world instead of focusing mechanistically on the acoustical/biological aspects of hearing.

As stated above, traditional approaches to hearing have led to the study of the capacities of the auditory system. These capacities may differ due to varying causes (e.g. age, congenital hearing impairments). The present study involves both "normal" and "impaired" hearing. In the introductory section we have already said that our investigation is primarily concerned with difficulties in perceiving everyday speech as experienced by the hearing-impaired individual. This means that as far as traditional studies of hearing are concerned we will focus on "impaired hearing". Besides, we should like to state explicitly that within the context of this study the notion "impaired hearing" will be used in its most general sense, i.e. different kinds of hearing impairment will not be taken into account.

As regards our interest in ecological approaches to hearing, we will come back to this later on. At this point we think it appropriate that before discussing different ways of dealing with hearing and hearing-impairment we first explain the background of this study together with what motivated us to embark upon it.

1.3. Background of the study

Let us begin by saying that, our background being phonetic, we have certain insights into "normal" speech perception, but are relatively novice as regards the perception of speech by the hearing-impaired. However, the question whether the results of phonetic research concerning the perception of speech by the normally hearing also apply in the case of the hearing-impaired seems valid to ask. It is common practice in studies concerning the perceptual abilities of the hearing-impaired to compare results obtained with normally hearing listeners to those of hearing-impaired listeners. As an example of research of this kind we should like to mention the work done in Sweden by Risberg and his associates (cf. e.g. Risberg and Agelfors, 1978 a,b; Risberg and Lubker, 1978).
As regards the perception of speech by the normally hearing, the attention of researchers in this field has increasingly been drawn to prosody during the past decade. Generally, the notion prosody is related to " a number of perceivable aspects of connected speech, most particularly those which cannot be assigned to individual speech sounds but rather are attributes of whole words and word sequences" (Nooteboom, Brokx and De Rooij, 1978: p. 77). On the sentence level prosody comprises aspects of timing, accent and intonation. Speech researchers have taken an interest in prosody for various reasons: partly because prosodic continuity proved to be essential to successful speech perception

(cf. Olive and Nakatani, 1974; Darwin, 1975; Nooteboom et al., 1978; Young and Fallside, 1980) and partly because prosodic factors appear to hold a key to improved speech synthesis but, equally importantly - in the psycholinguistic field - because of the role of prosodic knowledge in sentence processing (e.g. Cutler and Foss, 1977; Cutler and Norris, 1979; Cutler and Darwin, 1981). In their studies on prosodic factors speech researchers have focused on normally hearing listeners. Again, the question arises whether these factors contribute to a comparable extent to the listening strategy of the hearing-impaired. It was this question that provided the starting-point for our study. We decided to carry out an exploratory investigation in order to find an answer to the question whether some specific prosodic cues, viz. accent, pitch contour and speech rate, influence the speech decoding process of normally hearing and hearing-impaired listeners in a comparable manner or not.

Apart from mentioning results of studies dealing with the role of prosody in the listening strategy of the hearing-impaired, for which the reader is referred to the introductory sections of chapters III, IV and V, we should like to touch on some popular beliefs concerning the importance of prosodic factors. An advertising campaign in a number of leading Dutch papers shows a well-known actor who advises people that when communicating with hearing-impaired and/or deaf people they should take care that their faces are visible to the listener and they should speak slowly and clearly. In general when faced with a listener who appears to be unable to hear - and consequently understand - them, most people are inclined to increase the volume of their speech. Besides, a lower rate of speech is commonly believed to result in improved intelligibility on the part of the hearing-impaired. In chapter V results of research into the influence of speech rate on the perception of speech by the hearing-impaired will be reported on. All in all both everyday communication experience and evidence from studies concerning speech perception aroused our interest in the question whether prosody influences the speech decoding process of normally hearing and hearing-impaired listeners in a comparable manner. Before dealing with our way of approaching the above question, we feel it should be stated clearly that - within the context of this study - we shall not be concerned with lip-reading. As has already been mentioned we will try to find an answer to the question whether (some specific) prosodic cues are of comparable influence on the perception of speech by normally hearing and hearing-impaired listeners. By perception we understand auditory perception i.e. without the visual aid provided by lip-reading. However, our decision to opt for this approach is not meant to detract from the importance of lip-reading, a subject to which we will return in chapter IV, section 4.1.

In the following section of this chapter, the development of speech audiometry will be described both from a traditional and an ecological point of view. Besides, the line of approach to be followed in this study will be discussed and finally we shall give a summary of what will be dealt with in the following chapters.

1.4. A traditional approach

Apart from phonetics as a source of inspiration for our study we should also mention speech audiometry, i.e. the assessment of hearing by means of speech tests. Speech audiometry is used following pure-tone audiometry as a diagnostic aid, as a better means of assessing the social handicap, and in order to establish the benefit of a particular hearing aid. Speech audiometry as a means to assess the degree of social handicap implies trying to provide a measure of a hearing-impaired individual's ability to perceive speech in an everyday communication situation. In our opinion speech audiometric tests did not provide a reliable picture of the ability of the hearing-impaired testees to perceive everyday speech. As everyday speech consists of sentences and prosodic factors can be described as perceivable aspects of connected speech (e.g. sentences), it seemed reasonable to decide to investigate the influence of prosody.

Traditionally, the study of hearing has concentrated on the capacities of the auditory system and consequently - in case of reduced capacities - on quantitative methods to assess hearing loss. Assessment of auditory acuity is generally called audiometry. Audiometric tests can be divided into two main categories.

One category consists of non-verbal tests, i.e. not involving the use of language. Examples of tests belonging to this category are e.g. Moro's reflex, attention and orientation to sound, play audiometry, which are all used for the hearing evaluation of young children. By Moro's reflex is understood the reaction of infants to a variety of stimuli characterized by a sudden extension and abduction of the arms, hands, fingers and/or legs from their usual fixed posture. Moro's reflex is also known as a startle reflex (cf. also Nicolosi, Harryman and Kresheck, 1978). As regards non-verbal tests used for adults we should like to mention tympanometry, acoustic reflex testing and electric response audiometry. Tympanometry is an objective method for evaluating the mobility of the tympanic membrane and the functional condition of the middle ear. Acoustic reflex testing is a by-product of tympanometry and makes it possible to infer auditory pure-tone thresholds for the stimulated ear (i.e. the ear in which the reflex is to be obtained) from the stimulus level necessary to produce a response. Electric response audiometry involves the measurement of electrical activity of the auditory pathways in response to acoustic stimulation.

The other category comprises tests in which some verbalization is involved, viz. the understanding of instructions such as e.g. pure-tone threshold audiometry and differential pure-tone tests but also all tests involving the use and understanding of language such as e.g. all speech tests, self-appraisal questionnaires and appraisal of communicative skills by others. For a detailed review of the above the reader is referred to Catlin (1984). In the next section the emphasis will be on pure-tone tests as opposed to speech tests.

1.4.1. Pure-tone tests

An ever returning controversy in the field of speech audiometry is whether or not the assessment of hearing by means of pure-tone testing is valid for estimating the degree of hearing handicap for speech. In this context speech hearing handicap is understood to mean reduced ability to hear and understand speech under everyday conditions. The latter phrase is a metaphorical construction that really means speech as it is represented in various tests constructed with an eye to everyday usage and conditions.

Attempts to put an end to this controversy have mostly concentrated on trying to establish a clear relation between pure-tone audiograms and the speech reception threshold (SRT). The speech reception threshold is a traditional scoring method, which is defined as the level at which stimulus material - digits, spondaic or trochaic words, simple sentences or connected discourse - is correctly identified at the 50% level.

As to the SRT, Fletcher (1929) in his classic work "Speech and Hearing" postulates a close relationship between the .5, 1 and 2 kHz tonal thresholds and SRT. The generalizability of Fletcher's proposal is, however, uncertain in view of the specified nature of the disorders suffered by his listeners and the small number of the sample, viz. 10 subjects. In 1950, Fletcher returned with a more searching analysis of the problem from a mathematical point of view and with an impressive data base to back a conclusion that the .5 to 2 kHZ (the "three-average") system was valid in persons with relatively flat audiograms. In people with asymmetrical audiograms, however, the average of the two lower threshold levels from .5, 1 and 2 kHz predicted SRT better. Fletcher's (1953) system, which simply assigns weights to thresholds at octaves from .25 to 8 kHz yielded better predictions for both audiogram types (viz. flat and asymmetrical).

Fowler (1941) tries to make a case for preferring the test of tonal threshold to establish the percentage of disability, since he considers all other tests "undependable, in fact useless ..... basically unsound and misleading ....." (p. 938). Obviously, Fowler's aim too is to produce evidence for calculating the loss of capacity to hear speech on the basis of the pure-tone audiogram. Nevertheless, he shows speech test data that are in accordance with his calculations based on tonal thresholds only.

Noble (1978, ch. 6) mentions a number of more or less unsuccessful attempts at establishing a predictive relationship between tonal threshold and SRT, e.g. Steinberg and Gardner (1940), Hughson and Thompson (1942), Goldman (1944), Carhart (1946), Harris (1946), Palva (1952), Harris, Haines and Myers (1956), Graham (1960), Quist-Hanssen and Steen (1960), Young and Gibbons (1962), Siegenthaler and Strand (1964) and Carhart and Porter (1971). Noble himself considers the whole notion of SRT "nonrepresentative of daily life" and "insufficient as an everyday speech hearing measure" anyway (p. 140). However, Davis and Silverman (1978) in "Hearing and Deafness", which may be considered a reference book or a summary of the state-of-the-art of audiology, state in contrast to this that the correlation between tonal threshold and SRT is so good that the measure of the speech-reception threshold is redundant and therefore unnecessary in most cases.

As mentioned above Noble provides a comprehensive review of studies in this area. He concludes his review by saying that "thresholds at higher frequencies are the only ones showing more than chance association with discrimination ability ..... and the use of tonal threshold systems in general is inaccurate" (p. 169). Another slightly more recent survey of the literature by Hardick, Melnick, Hawes, Pillion, Stephens and Perlmutter (1980) indicates that SRT is highly predictable from pure-tone thresholds. However, the magnitude of this relationship is sensitive to a number of variables, including test reliability, audiometric pattern, age, method of presentation and the speech materials employed. Similarly it appears that 1000 and 2000 Hz are important frequencies for hearing suprathreshold speech. Smoorenburg, De Laat and Plomp (1982) discuss the relation between the tone audiogram and SRT in noise. They come to the conclusion that the correlation between the two is limited and that - consequently - prediction of SRT from the tone audiogram has only limited accuracy. Their findings imply that hearing loss above 2000 Hz has negative consequences for speech perception. In this context we should also like to mention the recommendation of the American Academy of Otolaryngology (AAO) for evaluating hearing handicap from pure-tone thresholds as discussed by Ward (1983). In its guide for the evaluation of hearing handicap (1979) the AAO defines handicap as "the disadvantage imposed by an impairment sufficient to affect the individual's efficiency in the activities of daily living". In order to determine the handicap, hearing threshold levels are to be measured at 500, 1000, 2000 and 3000 Hz in each ear. In his discussion Ward also mentions evidence from studies by Niemeyer (1967), Lindeman (1969), Acton (1970), Aniansson (1974), Findlay and Denenberg (1977) and Suter (1978), showing that the capacity of hearing at 4000 Hz can be important to the understanding of ordinary speech under conditions of masking.

Returning to our starting-point, viz. the controversy as regards the relation between pure-tone thresholds and everyday speech perception, we are forced to conclude that a satisfactory answer has not been found yet. We therefore decided that our analysis should also include a comparison between experimentally obtained test scores and pure-tone audiograms of hearing-impaired subjects. The results of this comparison will be discussed in chapter III.

1.4.2. Speech tests

1.4.2.1. Introduction

While trying to become acquainted with the field of audiometry, we soon discovered that the question as to what kind of test material would be most suitable to be used for the purpose of speech audiometry still remained open. Over the years a variety of tests have been developed and various factors have been considered which might play an important role in speech intelligibility testing. We will therefore start by giving a brief review - without any pretension to completeness - of the development of speech audiometry and by mentioning some of the factors that have received most attention.

1.4.2.2. Development of speech audiometry

The first systematic attempts at obtaining precise, quantifiable measurements of speech intelligibility were made by Campbell (1910) with a view to establishing practical methods of evaluating the effectiveness of telephone channels. In subsequent years much research was done in order to refine the methods as established by Campbell, most notably at Bell Telephone Laboratories (cf. Fletcher, 1929; Fletcher and Steinberg, 1929). The latter two also developed word and sentence lists for intelligibility testing. Another major contribution to the development of speech testing procedures was the extensive battery of tests developed by the Harvard Psychoacoustic Laboratory (PAL) during World War II. These tests were originally designed for the purpose of evaluating military communication systems. Included in the test battery were nonsense syllable lists, phonetically balanced (see section 1.4.2.3) word lists (the so-called PAL PB-50 lists), spondaic word lists and phonetically balanced sentence lists. For a detailed discussion of the test material the reader is referred to Egan (1948). The PAL PB-50 lists emphasized the necessity of strict adherence to phonetic balance, i.e. occurrence of sounds within a list at the same relative frequency as in a representative sample of English speech. Hirsh, Davis, Silverman, Reynolds, Eldert and Benson (1952) criticized this test for lack of familiarity of certain test items as well as variability of recordings. Their test, the CID (Central Institute for the Deaf) Auditory Test W-22, used only words that met the criteria of word familiarity, more rigid phonetic balance within each list, and improved recording techniques. The CID W-22 test is still one of the most commonly used audiometric tests in the USA (cf. Martin and Forbis, 1978). Fry and Kerridge (1939), drawing on Fletcher's work, constructed phonetically balanced sentence lists that were to play an important role in the British Medical Research Council study on the evaluation of hearing aids (cf. also Fry, 1964, for PB monosyllabic word lists). Of course other countries had to develop their own speech material in the appropriate languages.

With regard to the development of speech audiometry in the Netherlands, the reader is referred to chapter II, which is concerned with an analysis of one of the most widely used Dutch set of PB word lists.

From the fifties onwards various studies have been carried out to investigate the reliability of speech audiometric tests as a means of measuring speech discrimination abilities of the hearing-impaired. We will now mention some of the factors that are generally considered to be of importance in speech intelligibility testing.

1.4.2.3. Phonetic balance

The word and sentence lists that have been used for audiometric purposes are generally claimed to be phonetically balanced, i.e. the phonetic content has been balanced in such a way as to reflect the distribution of phonemes that occur in the language concerned. Before mentioning some examples of studies dealing with the phonetic balance of word and sentence lists, we will first enlarge upon the notion "phonetic balance". As far as PB word lists are concerned the notion phonetic balance is generally used to indicate that the frequency with which the phonemes occur in the lists corresponds with their frequency of occurrence in a representative sample of the language at issue. Usually, this is accomplished simply by assigning a certain over-all proportion to each phoneme in the list without regard for the internal phonemic make-up of words. However, more recent research has shown that coupling effects exist for different consonant and vowel sequences and that the articulatory and acoustic properties of a given phoneme often depend on those of its neighbours. This means that apart from being phonetically balanced, word (and/or sentence) lists should also be balanced as regards the frequency of occurrence of certain combinations of phonemes.
Lehiste and Peterson (1959) considered the phonetic balance of the PB lists to be very limited and devised ten 50-word lists exclusively consisting of monosyllables of the CNC (consonant-vowel nucleus-consonant, their terminology) type. The distribution within each list was according to the first order of phonemic balancing, i.e. each initial and final consonant and each vowel nucleus occurred with the same frequency within each list. The original CNC lists were revised in order to achieve a more uniform

distribution of word familiarity while maintaining phonemic balance (Peterson and Lehiste, 1962). Elkins (1970) analyzed the revised CNC lists as to phonetic balance and word familiarity. His results indicate generally good phonetic balance with respect to the English language and uniformity as regards word familiarity. In this context we should like to mention Lyregaard, Robinson and Hinchliffe (1976), who consider phonemic equalization to be more important than phonetic balance. By phonemic equalization they understand that the relative occurrence of phonemes in each list is balanced with those in every other list belonging to the same test. Gay (1970) also criticizes the phonetic balance of the so-called PB word lists. In his opinion more attention should be paid to the influence of coarticulation as "it is not unreasonable to suspect that conditions may exist where the perception of a given sound might be either enhanced or degraded by the coarticulation effects of the adjacent phoneme" (p. 993). In a recent study by Causey, Hood, Hermanson and Bowling (1984) coarticulation is also mentioned as a factor that has received too little attention in monosyllabic word recognition tests. Kalikow, Stevens and Elliott (1977) state that it is well-known that the intelligibility of a word in noise (as e.g. in an everyday situation) depends on the sequence of sounds that constitute the word. As some classes of sounds are more susceptible to masking by noise than others, words containing these sounds are likely to be less intelligible. Consequently - when selecting material for speech intelligibility tests - attention must be paid to selecting material in which the phonetic content is balanced to reflect the distribution of speech-sound classes that occur in the language. Van Dijkhuizen, Van Loon and Schelvis (1985) stress the importance of "internal" phonetic balance, i.e. all phonemes occur with the same frequency in each of the sublists forming part of a set of PB word lists. They state that differences in phoneme distribution between sublists may cause the average intelligibility scores to vary per sublist. We will come back to this subject in chapter II.

1.4.2.4. Word familiarity

The intelligibility of words is - among other things - influenced by their familiarity. A number of investigators have shown the effect of word familiarity using as a measure of familiarity the relative frequency of occurrence of a word in specified kinds of spoken or written language (cf. Howes, 1957; Owens, 1961; Epstein, Giolas and Owens, 1968). The influence of word familiarity will be dealt with in greater detail in chapter II.

1.4.2.5. Speaker variability

As regards the matter of increased variability introduced by listening to different speakers, there can be no argument that such an effect is substantial. The classic instance is the different results obtained with the two recordings of the PAL-monosyllables, viz. Davis (1948) vs. Hirsh et al. (1952). House, Williams, Hecker and Kryter (1965) found that whereas different recordings by the same speaker resulted in no significant variation in test results, the variation in response to lists read by two different speakers was considerable. Kreul, Bell and Nixon (1969) also observed significant differences in listener performance when the same lists were presented read out by different speakers. Fourcin (1976) considers speaker variation an important variable in speech intelligibility tests because "detailed study of speech, even when provided by a phonetically trained speaker shows that utterances have important dissimilarities" (p.48). Hood and Poole (1980) state that whereas "intrinsic" intelligibility has been attributed to the particular structure of the word, word familiarity and word environment, "perceived" intelligibility will be influenced by intersubject variability and influence of the speaker. In this context we should also like to mention the experimental findings reported by Van Dijkhuizen et al. (1985), which illustrate that intelligibility scores obtained in speech audiometry tests may be dependent on the speaker used. We will come back to the subject of speaker variability in chapter III.

1.4.2.6. Interlist consistency

Another important factor in speech intelligibility tests is the consistency in subject's performance from one list to another, i.e. do different lists belonging to the same test yield the same average intelligibility scores for the same subject. Elpern (1960) comparing results from the four CID W-22 monosyllable lists found that the lists differed significantly both in terms of average scores and range of difficulty. The results of Ross and Huntington (1962) assessing the interlist consistency of the same material showed significant differences in mean scores between the four lists; only list 3 and 4 appeared to be roughly equivalent. Maximum interlist equivalence was one of the primary considerations in the development of the NU (Northwestern University) Auditory Tests No. 4 and No. 6 (Tillman, Carhart and Wilbur, 1962; Tillman and Carhart, 1966). Grimes, Mueller and Williams (1984) presented the Auditec of St. Louis recording of the 60% time-compressed NU 6 test to normal subjects and subjects with sensorineural hearing loss. It appeared that only lists I and IV were equivalent for both groups. They conclude that choice of list should be one of the considerations in the use of time-compressed speech material. Causey et al. (1984) in an evaluation of the Maryland CNC test found that only 6 out of 10 test lists appeared to be approximately equivalent.

Examination of the mean raw score differences among these 6 lists shows a range of 3.6%, which they consider a poor value. Interlist consistency will be dealt with in chapter II in relation to one of the most commonly used Dutch PB word lists.

1.4.2.7. Response mode

Among the various alternative types of speech tests developed during the fifties and sixties were also speech tests using a closed-response set format. In this type of test the subject is asked to identify the test item presented from a written list of alternatives. Fairbanks (1958) devised the original closed-set "rhyme test". This was modified by House et al. (1965) and again by Kreul, Nixon, Kryter, Bell, Lang and Schubert (1968). Gengel (1973) in one of the first studies concerning the clinical reliability of tests of the closed-response-set format comments that a closed-set approach ought perhaps to reduce variability by preventing "cognitive variables" from interacting with "clinical variables" (see also next section). However, his results fail to confirm this expectation. As regards our own experiments (for which see chapters III, IV and V) we decided to ask our subjects to write down whatever they heard after every test item. This response mode was chosen in order to exclude the possible influence of differences in verbal ability between our subjects. For results illustrating the importance of verbal ability as a variable in speech audiometry tests the reader is referred to Van Dijkhuizen et al. (1985).

1.4.2.8. Intersubject variability

Another important source of variability in speech intelligibility testing is constituted by what could be called subject-related factors. By subject-related factors we understand - of course - individual differences in hearing acuity (the clinical variables), which may account for significant differences in performance but also the degree to which subjects are able to make use of linguistic and contextual constraints in understanding sentences (the cognitive variables). Besides, it is generally known that people have different vocabulary sizes due to, among other factors, age differences, i.e. an individual's vocabulary increases with increasing age, education and intelligence. On the other hand, greater age is also known to have a negative influence on response speed (cf. Newman and Spitzer, 1983). These are only a few examples of the possible influence of subject-related factors in testing speech perception. In our discussions of the results of our experiments (cf. chapters III, IV and V) we will return to the question of intersubject variability.

1.4.2.9. Sentence context

Another important factor in speech intelligibility tests is the effect of sentence context. It is generally known that words in a sentence context are more intelligible than words spoken in isolation (cf. Miller, Heise and Lichten, 1951; Gladstone and Siegenthaler, 1971). They argued that the sentence context imposes constraints on the set of alternative words that are available as responses at a particular location in a sentence, and noted that the intelligibility of words increases when the number of response alternatives decreases. This conclusion was supported and further quantified by Duffy and Giolas (1974), who investigated the relationship between word predictability and sentence intelligibility. Their experiments showed that the intelligibility of a word is influenced by its predictability. The same conclusion can be drawn from Kalikow et al. (1977), who developed a test of speech intelligibility with controlled word predictability. The purpose of the SPIN (speech perception in noise) test as developed by Kalikow et al. was to test speech reception using sentences that simulate a range of contextual situations encountered in everyday speech communication. The SPIN test differs significantly from conventional ways of assessing speech discrimination employing PB word lists, in which the emphasis is on the measurement of the acoustic-phonetic elements in speech. However, speech intelligibility tests using isolated words have been criticized as having little prognostic value as regards the ability to perceive everyday speech, in which phonological, lexical, syntactic and semantic cues play an important role. Results as presented by Hutcherson, Dirks and Morgan (1979), who investigated the effects of presentation level and signal-to-babble ratio on the SPIN test, show that SPIN test scores may provide a more insightful estimate of the ability of the hearing-impaired to perceive speech in everyday listening situations than is available from conventional monosyllabic word lists. We will return to the issue of sentence context when describing the test material used in our experiments in chapters III and IV.

1.4.2.10. Noise

As has already been stated in the introduction an everyday listening situation is usually characterized by noise that interferes with the understanding of speech. Hearing-impaired people (with or without a hearing aid) often complain about the difficulty of understanding speech in a noisy environment (Plomp, 1978). However, in speech audiometric tests carried out under good conditions, i.e. without noise, at comfortable speech levels, with listeners having fairly good hearing, the intelligibility scores in many cases reach 100%. Ceiling effects of this kind make it difficult to detect small differences such as e.g. in the case of (near) normally hearing listeners differences between the two ears of the listener, left and right ear advantage, and as far as hearing-impaired listeners are concerned, differences between two hearing aids which are being tested etc. A commonly adopted method to solve this problem is to mask the speech signal with noise. An extensive study by Plomp (1978) shows the possibility to use the speech-reception threshold in noise to predict the possible benefit of hearing aids. Evidence from various reports by Plomp and his associates (Plomp, 1978; Plomp and Mimpen, 1979; Plomp and Duquesnoy, 1982; Smoorenburg et al., 1982) shows that listeners with even mild sensorineural hearing loss may experience more difficulty in perceiving speech in noisy environments than normally hearing listeners do. Dubno, Dirks and Morgan (1984) report results of measurements of speech recognition in quiet and in noise for subjects divided into groups on the basis of age and hearing status. Their results show that the ability to understand speech in difficult listening situations is determined not only by audiometric findings but also by the age of the listener. They conclude by saying that "the identification of subtle communication difficulties not revealed by the standard evaluation may enable the clinician to provide more insightful counseling, thus allowing the individual listener to develop more realistic expectations of performance in difficult communication settings" (pp. 95 and 96). We will come back to the use and effects of noise in speech intelligibility tests in the discussion of our test material (see chapters III and IV).

1.5. An ecological approach

As stated in the introductory section ecological approaches to hearing try to produce adequate accounts of the real world to be perceived, or - more accurately - the world available for human perception. This means that attention is focused on "what people do" in the real day-to-day world instead of studying the physiological capacities of the auditory system in isolation. By "what people do" is understood the various auditory acts performed by people - in relation to the audible world - such as listening and communicating. An approach of this kind clearly differs from the one that begins with an anatomical study of the ear and a description of how the auditory system functions. In our discussion of an ecological approach to hearing as opposed to traditional ways of dealing with hearing we shall be following the line of thought as pursued by Noble (1978; 1983).

In his book "Assessment of impaired hearing" Noble (1978) reviews the theory and practice of current hearing assessment. Apart from reviewing methods employed in hearing assessment, he also provides a basis for an approach to hearing which instead of focusing on the mechanical testing of aspects of hearing concentrates on people's own experiences and appraisals of their hearing and their difficulties in hearing. Dealing with traditional tests of hearing Noble claims that they are "off target as regards everyday hearing experience". In his opinion hearing tests in spite of obvious advantages such as ease of administration, scoring etc. do not provide an adequate measure of hearing function. In this context he states that the endeavours to simplify procedures may well have compromised the value of hearing tests. With regard to pure-tone tests - one of the most commonly used types of hearing tests - he says that their validity as a measure of hearing ability is still a controversial issue. As regards speech tests he is of the opinion that standardization has probably caused these tests to be increasingly unrelated to everyday hearing experience. On the one hand pure-tone tests offer standardization and - at times - diagnostic validity whereas on the other hand they are obviously unrelated to everyday hearing experience. The same ambivalence can be found in speech tests. Speech material as used in audiometric tests having high test reliability does not have anything in common with everyday speech whereas speech tests trying to emulate everyday conditions provide such variable results that no firm conclusions can be drawn from them. In view of this, Noble without pretending to have found a lasting satisfactory answer proposes a radical alternative to traditional tests, viz. self-report. Self-report means asking people suffering from a hearing impairment after their experiences, i.e. what they experience when performing hearing acts such as listening, communicating in the everyday world. Noble describes self-report as one of the oldest devices known to man which has been used both in medical and social sciences. With regard to hearing ability self-report was initially used to find a way of labelling different tonal threshold level ranges and later as a means to assess the validity of various tests and systems. The lists of questions employed in self-report are called questionnaires. Questionnaires can be divided into two categories, viz. scaled and non-scaled questionnaires. A scaled questionnaire does not only try to assess the occurrence of a certain phenomenon but also the extent to which it is experienced by the population in question. Consequently, a scaled questionnaire of hearing loss provides a quantitative measure of the degree of manifestation of that loss in the individual. Non-scaled questionnaires can only quantitatively describe the response of a certain population to a list of questions. Noble (1978) gives a review of the development of self-report questionnaires. He describes the Hearing Handicap Scale constructed by High, Fairbanks and Glorig (1964) as a "landmark in the assessment of adult hearing" (p. 250). The purpose of this self-report scale was to obtain better evaluations both of people that were to undergo treatment and of those already experiencing treatment. Another well-known questionnaire mentioned by Noble is the

Social Hearing Handicap Index reported by Ewertsen and Birk-Nielsen (1973), which does not differ much from the Hearing Handicap Scale. Finally, Noble presents a new version of the Hearing Measurement Scale which was first described in Noble (1968). The new scale consists of 42 questions (arranged in seven sections) concerning various aspects of hearing difficulty and reaction to that difficulty. For a more elaborate description of the above-mentioned self-report scales as well as their historical development the reader is referred to Noble (1978). In recent years, self-report has been regarded as an alternative assessment method in its own right.

1.6. Aims of this study

As we have already said, our inspiration to embark upon this study comes from two different - but in many ways related - disciplines, viz. phonetics and (speech) audiometry. Phonetic research into the field of prosody aroused our interest in the question whether prosodic factors obviously influencing the perception of speech by normally hearing listeners can be shown to play a comparable role in the perception of speech by hearing-impaired listeners. Criticism concerning existing speech audiometry tests motivated us to perform an exploratory study in order to find out more about what factors influence the perception of speech by the hearing-impaired with a view to possible incorporation of results in test material to be used for audiometric purposes. By speech we understand connected speech (sentences) as we should like speech audiometry tests to have more predictive validity as regards performance in everyday conversation situations. Our interest in ecological approaches to hearing should also be seen in this light. According to Noble (1978; 1983), advocating an ecological approach to hearing, traditional speech tests do not provide a reliable picture of everyday hearing experience. He proposes the self-report method as an assessment tool with regard to hearing loss and handicap in the day-to-day world. Our hope is that the results of the experiments to be reported on here will contribute to the ultimate construction of material that does give a realistic estimate of a hearing-impaired person's ability to understand speech as it occurs in everyday communication situations.

1.7. Brief outline of the study

In the next chapter we will review the development of speech audiometry in the Netherlands. Besides an analysis of one of the most commonly used sets of Dutch PB word lists will be reported on.
In chapter III we will start the survey of our own experimental work with a report of our first experiment concerning the influence of accent on the speech decoding process of normally hearing and hearing-impaired listeners.
Chapter IV will deal with the results of our second experiment carried out to investigate the role of pitch contours in the perception of speech by normally hearing and hearing-impaired listeners.
In chapter V we will discuss the results of our third and last experiment dealing with the influence of speech tempo on the perception of speech by normally hearing and hearing-impaired listeners.
In our sixth and final chapter we will try to point out in what way the conclusions obtained from our experimental work can be related to what has been stated in chapter I and we will give suggestions for further investigation.

experience) of these self-assessments in [illegible] to
Besides these self-assessments in the daily routine, our
score is that the [illegible] ability of the [illegible] to be
reported on [illegible] will [illegible] be ultimate
quantification of [illegible] that [illegible] as absolute
estimate of the subject's general ability to
understand speech as it occurs in everyday communication
situations.

1.7 Organisation of the study

In the next chapter we will review the development of speech audiometry in the Netherlands. Besides, an analysis of one of the most commonly used sets of Dutch PB word lists will be reported on.

In chapter III, we will start the report of our own experimental work with a series of our first experiment concerning the influence of several on the speech decoding process of normally speaking and hearing impaired listeners.

Chapter IV will deal with the results of a second experiment concerning this influence in the perception of speech by normally hearing and hearing impaired listeners.

In chapter V we will discuss the results of one third and last experiment, dealing with the influence of speech tempo on the perception of speech by normally hearing and hearing impaired listeners.

In the sixth and final chapter we will try to point out in what way the conclusions obtained from our experimental work can be related to what has been stated in chapter I, and we will give suggestions for further investigations.

Chapter II

Examination of Dutch word lists currently used in speech audiometry

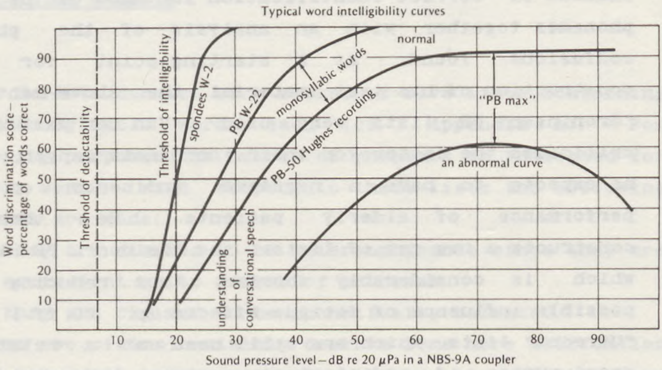
2.1. Introduction

As described in chapter I, the test material used in speech audiometry generally consists of lists of spoken words or (less usually) sentences. Looking at speech audiometry tests from a phonetic point of view, we are inclined to advocate the use of sentences over isolated words since the former enable us to investigate the contribution of prosodic factors to speech perception. Moreover sentences, being representative samples of everyday speech, approach a normal conversation situation as experienced by the hearing-impaired more closely than lists of words spoken in isolation (cf. Bench and Bamford, 1979). Approaching speech audiometry from a completely different angle, Crul (1983) states that the advantage of using monosyllables - when measuring speech intelligibility - is that information such as provided by accent, pitch patterns and temporal cues is not allowed to interfere with phoneme perception. Since the aim of this study is to gain insight into the influence of prosodic patterns on the perception of speech by the hearing-impaired, possibly with a view to the compilation of material for speech audiometry tests, we decided to make an inventory of the test material used for the purpose of speech audiometry in the Netherlands.

From the fifties onwards various kinds of speech tests have been developed. In most cases the material used for these tests consisted of lists of either monosyllabic words or words with two syllables (spondees). These lists are generally known as PB word lists (Egan, 1948) and are still commonly used in speech audiometry.

The abbreviation PB stands for phonetically balanced, which means that the frequency of occurrence of the phonemes in the lists is claimed to be representative of the frequency of occurrence of phonemes in general language use (Noble, 1978). The underlying rationale of this balancing is that if a listener were totally unable to perceive a particular phoneme which occurs only infrequently in natural language his handicap is less severe than if the phoneme had been a more frequent one. The words of these PB lists are presented to patients monaurally via headphones, masked or unmasked depending on the test situation, and the percentage of correctly repeated phonemes serves as an indication of a patient's hearing acuity.

This method of scoring is similar to what is generally called the assessment of the threshold of intelligibility of speech, sometimes also defined as the speech reception threshold (SRT). Less often used in clinical audiology and speech audiometry are the threshold of detectability and perceptibility. The threshold of detectability is defined as the level at which the listener detects the presence of speech half of the time, whereas the threshold of perceptibility is obtained by using continuous discourse and is defined as the level at which the listener is just able to understand the discourse with effort. According to Egan (1948) the threshold of perceptibility is about 8 dB higher than for detectability; the threshold of intelligibility is 4 dB above perceptibility. Figure 2.1 shows the typical hearing curves as given by Davis and Silverman (1978: p. 214).



<u>Figure 2.1</u>: The sound pressure level for speech tests is defined relative to 20 μ Pa for the calibration point (1000 Hz). The curve for spondees rises more steeply than for monosyllables. The threshold of intelligibility for simple sentences and for connected discourse (SRT) is practically the same as for spondees. For monosyllables the steepness and position of the curve vary from one talker or list of words to another. For some abnormal ears the curve goes through a maximum and falls again at high speech levels. The plateau or maximum is called the "PB max", i.e. maximum for phonetically balanced word lists (Davis and Silverman, 1978, p. 214).

In the Netherlands alone a miscellany of PB lists are in use; the historical development of which we shall summarize only very briefly. Reijntjes (1951) gives a critical survey of the development of speech audiometry and introduces the "Groningen" PB lists (p. 125 ff.). Kruisinga (1955) discusses the various methods used in both tone and speech audiometry and introduces a new method, which he labels "qualitative" speech audiometry. The method described involves the measurement of the chances of correct identification for each of the Dutch phonemes together with an analysis of the phoneme confusions found. As a starting-point for the construction of his test material the above-mentioned "Groningen" PB lists were used. Van der Waal (1962) criticizes the latter for their inordinate length, which he expects to have a negative influence on the performance of elderly patients. He therefore constructs a new set of lists: the "Leiden" PB lists, which is considerably shorter, thus reducing the possible influence of fatigue effects (p. 50 ff.). The "Utrecht" lists, which are still used at a relatively great number of audiological centres and otological clinics, were compiled by J.J. Groen and A.C.M. Hellema at the Department of Otolaryngology of the University Hospital of Utrecht. Unfortunately, the exact date could not be established. Up to the present moment investigations have been carried out aiming at a standardized set of PB word lists. Crul (1983) compiled a standardized speech audiometry test for children aged between three and six and a half. Van Dijkhuizen et al. (1985) analysed three much used sets of Dutch PB word lists as to - among other things - average intelligibility scores, possible influence of speaker variation, phonetic balance and scoring method employed. As one of the long-term aims of this study is that the results obtained might be incorporated in the construction of speech audiometric tests, we wanted to investigate some of the claims made with regard to the PB word lists used in the Netherlands. Since there is a variety of lists in current use for the purpose of speech audiometry, a choice had to be made as to which set of lists should be taken into consideration for a critical analysis. The so-called Utrecht lists (henceforth U-lists) seemed to be a good starting point: they are used at a relatively great number of otological clinics, and staff members of these clinics showed themselves willing to co-operate.

2.2. The U-lists

The U-lists consist of a subset of five lists containing 80 monosyllabic words each (cf. Appendix A). For scoring purposes the number of phonemes is indicated for every word. With respect to these lists the following claims are made:

1) they are claimed to be interchangeable since they are equivalent as to number of phonemes.
2) they are claimed to be phonetically balanced.

These two claims certainly deserve some more elucidation and are worth being critically looked at. Furthermore we will be concerned with the frequency of occurrence of the words used in the U-lists, i.e. - as far as our investigation is concerned - the question whether the words occurring in the U-lists can be considered representative of normal language use.

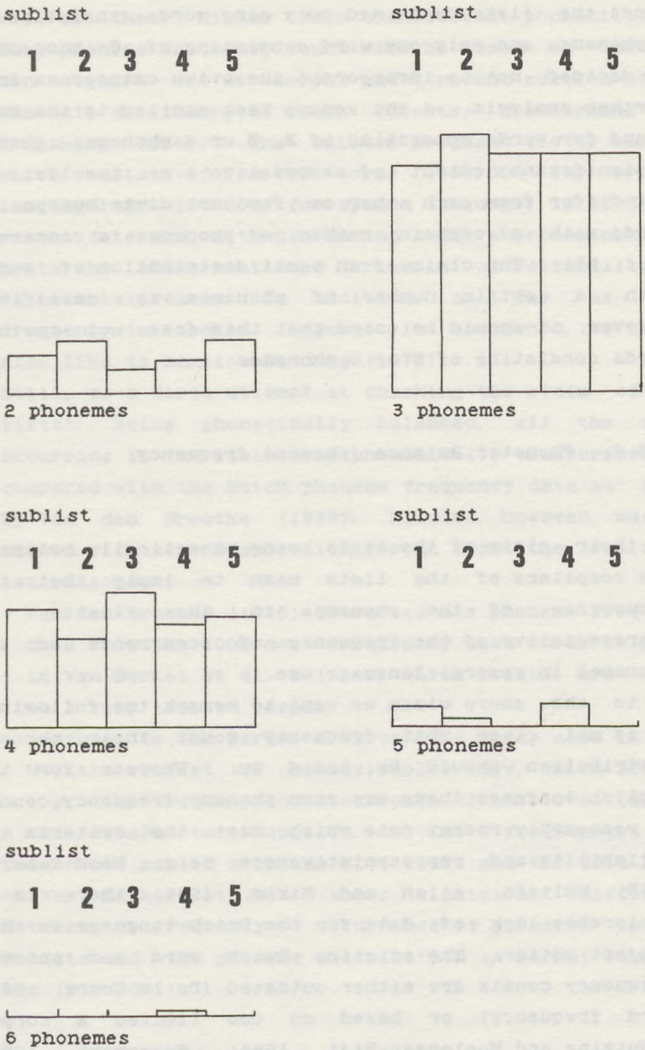
2.3. Analysis of the U-lists

2.3.1. Number of phonemes

In order to investigate the distribution of words consisting of a certain number of phonemes over the five lists, the total number of occurrences of words was counted per word length in phonemes, per list and for all the five lists together. Table 2.1 shows the results; columns indicate the word length in phonemes, whereas each row represents one individual sublist. The bottom row indicates the total number of words occurring per word length in phonemes for each of the five sublists and for all the five sublists together.

Table 2.1: Distribution of words per word length in phonemes over the five U-lists (total number of words: n=400).

list	word length in phonemes 2	3	4	5	6	total
1	7	45	24	4	0	80
2	10	52	18	0	0	80
3	4	48	27	1	0	80
4	6	48	21	4	1	80
5	10	48	22	0	0	80
total	37	241	112	9	1	400



<u>Figure 2.2</u>: Distribution of words per word length in phonemes over the five U-lists.

Since the lists contained only nine words consisting of 5 phonemes and only one word consisting of 6 phonemes, we decided not to incorporate these two categories in a further analysis. A chi square test applied to the data found for words consisting of 2, 3 or 4 phonemes showed a significant extent of association i.e. the lists do not differ from each other as far as distribution of words with a certain number of phonemes is concerned ($p < .05$). The claim of an equal distribution of words with a certain number of phonemes is justified. However, it should be noted that this does not include words consisting of 5 or 6 phonemes.

2.3.2. Phonetic Balance (phoneme frequency)

By their claim of the lists being phonetically balanced the compilers of the lists mean to imply that the occurrence of the phonemes in the lists is representative of the frequency of occurrence of the phonemes in general language use.
As to the above claim we want to remark the following: it is not clear what frequency count their phoneme distribution should be based on. Whereas for the English language there are some phoneme frequency counts of reasonably recent date which meet the criteria of reliability and representativeness (e.g. Hood Robert, 1965; Hultzén, Allen and Miron, 1964) there is a deplorable lack of data for the Dutch language in this subject matter. The existing Dutch word and phoneme frequency counts are either outdated (De la Court, 1937, word frequency) or based on too limited a corpus (Huizing and Moolenaar-Bijl, 1944; Eggermont, 1956, and Oosterlynck, 1962, phoneme frequency; Van Berkel, Brandt Corstius, Mokken en Van Wijngaarden, 1965, word frequency). It might be worth mentioning in this context that a project was started at the Institute of Phonetics of the University of Utrecht in 1983 with the aim of providing a frequency count of Dutch phonemes as

well as their higher order transitional probabilities. This phoneme frequency count will be based on the Uit den Boogaart (1975) corpus and a recent edition of the Van Dale dictionary of Dutch (Geerts, Heestermans and Kruyskamp, 1984). The Uit den Boogaart (1975) corpus, which consists of 720.000 words (600.000 for written language and 120.000 for spoken language) is of fairly recent date and, although having some shortcomings, it meets the above-mentioned criteria of reliability and representativeness. In addition, as far as word frequency in spoken language is concerned, we should also like to mention De Jong (1979).

Still, as a first attempt at checking the claim of the lists' being phonetically balanced, all the words occurring in the lists were phonemically transcribed and compared with the Dutch phoneme frequency data as given by Van den Broecke (1976). Results, however, must be viewed with some reservation for at least the following two reasons:

- Van den Broecke (1976) extracted his phoneme frequency data from the 1000 most frequently used words as given in Van Berkel et al.'s lists, which itself are based on a very limited corpus.
- contrary to Van Berkel's lists, the words used in the U-lists consist of monosyllables only, which affects e.g. the frequency of occurrence of the vowel [ə].

A chi square test applied to the frequencies of occurrence pooled over the five lists and the data based on Van Berkel et al. shows significant difference between the frequency of occurrence of phonemes in the U-lists and the phoneme distribution in normal language use ($p < .001$).

2.3.3. Frequency of occurrence (word frequency)

Apart from investigating whether the occurrence of the phonemes in the U-lists can be considered representative of the frequency of occurrence of phonemes in general language use, we also wanted to find out whether the words in the U-lists can be regarded as representative of everyday language use. We are of the opinion that the argument used to emphasize the importance of phonetic balancing, viz. the supposed relation between the frequency of occurrence of phonemes and their perception (see also section 2.1) may also prove to be valid in the case of words. It may well be possible that the occurrence of a large number of highly infrequent words in a speech audiometry test influences the correct perception of the test words negatively.

A way of finding out whether a word can be considered representative of normal language use is to assess its frequency of occurrence in the language concerned. The frequency of occurrence of words in a particular language is determined by performing large counts based on extensive language corpora.

The frequencies of occurrence of the 400 words occurring in the U-lists were looked up in the Uit den Boogaart (1975) word frequency count, which gives separate numbers for occurrence in written language and spoken language. Within the context of this investigation "normal language use" will be defined as the way in which the words of the Uit den Boogaart corpus are distributed over the frequencies of occurrence as given in the E-list of frequency classes (p. 467 ff). For this purpose the total range of frequencies occurring in the E-list (1 - 2000 and higher) was logarithmically divided into classes in the following way: 1-4; 5-8; 9-16; 17-32; 33-64; 65-128; 129-256; 257-512; 513-1024; 1025-2048; 2049-4096. As only very few words had a frequency of occurrence higher than 4096, we decided to limit our range of frequency classes accordingly. For each class, the number of occurring words was counted both for written and spoken language, for the U-lists and the Uit den Boogaart corpus respectively. The results are given in tables 2.2 and 2.3 and graphically represented in figures 2.3 and 2.4.

Table 2.2: Total number of words (in %) per frequency class for the U-lists and the Uit den Boogaart corpus respectively; for spoken language only.

frequency class	U-lists n=257	Uit den Boogaart n=11.886
1-4	38	83
5-8	15	7
9-16	11	4
17-32	4	2
33-64	8	2
65-128	6	0.9
129-256	5	0.5
257-512	5	0.3
513-1024	3	0.1
1025-2048	3	0.2
2049-4096	2	-

Table 2.3: Total number of words (in %) per frequency class for the U-lists and the Uit den Boogaart corpus respectively; for written language only.

frequency class	U-lists n=316	Uit den Boogaart n=78.913
1-4	15	87
5-8	15	6
9-16	13	3
17-32	12	2
33-64	14	1
65-128	9	0.5
129-256	5	0.3
257-512	6	0.1
513-1024	4	0.06
1025-2048	3	0.08
2049-4096	4	-

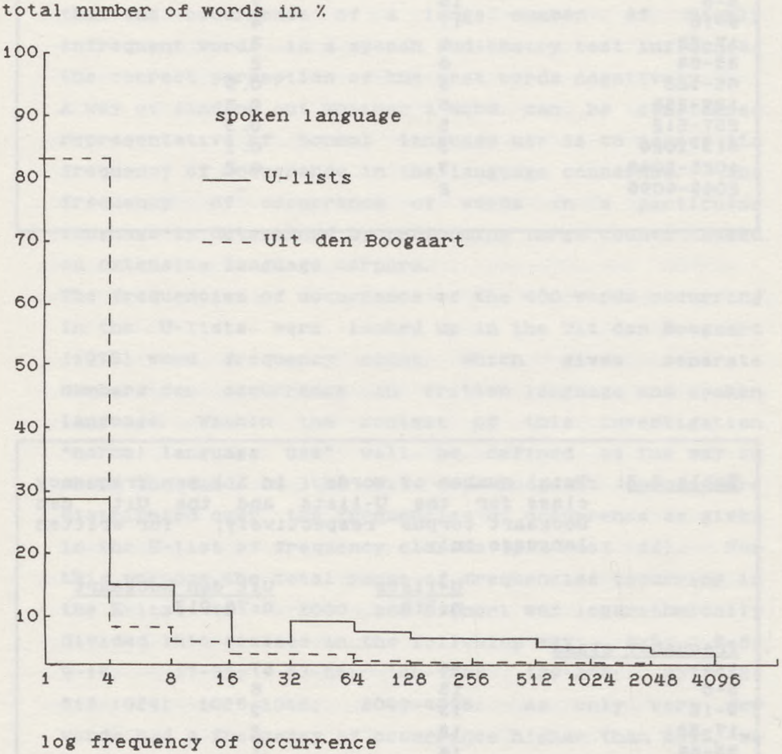


Figure 2.3: Distribution of the words in the U-lists (thick line) according to the frequency of occurrence of each word as given for the Uit den Boogaart corpus. The distribution of the words from the Uit den Boogaart corpus itself is presented as a dashed line.

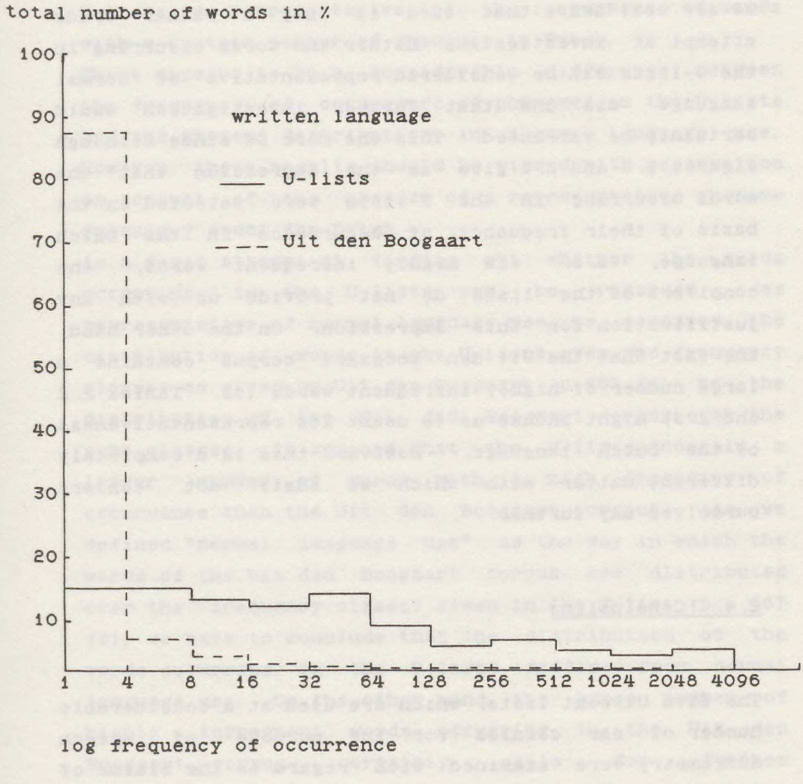


Figure 2.4: Distribution of the words in the U-lists (thick line) according to the frequency of occurrence of each word as given for the Uit den Boogaart corpus. The distribution of the words from the Uit den Boogaart corpus itself is presented as a dashed line.

Figures 2.3 and 2.4 show a considerable difference in distribution over the frequency classes between the words occurring in the U-lists and the Uit den Boogaart corpus. The U-lists appear to contain a larger number of "more frequent" words (i.e. with a high frequency of occurrence) than the Uit den Boogaart corpus whereas the latter contains substantially more "less frequent" words (i.e. with a low frequency of occurrence).
We are well aware that ours is only a rather crude attempt at investigating whether the words occurring in the U-lists can be considered representative of normal language use and that further investigation would certainly be warranted. This the more so since although figures 2.3 and 2.4 give us the impression that the words occurring in the U-lists were selected on the basis of their frequency of occurrence in the Dutch language, i.e. few highly infrequent words, the compilers of the lists do not provide us with any justification for this impression. On the other hand, the fact that the Uit den Boogaart corpus contains a large number of highly infrequent words (cf. Tables 2.2 and 2.3) might induce us to doubt its representativeness of the Dutch language. However, this is a completely different matter with which we shall not concern ourselves any further.

2.4. Conclusions

The five Utrecht lists, which are used at a considerable number of ear clinics for the purpose of speech audiometry were examined with regard to the claims of their being equivalent as to number of phonemes and phonetic balance. Besides, a first attempt was made to investigate whether the 400 words occurring in the U-lists can be considered representative of normal language use.
Analysis of number of phonemes of the words occurring in the five lists showed a significant extent of

association i.e. the lists do not differ from each other as far as distribution of words with a certain number of phonemes (i.e. 2, 3 or 4) is concerned. As the U-lists contain only nine words with 5 phonemes and only one word with 6 phonemes, these words were not taken into consideration. In this context it might be interesting to find out whether the distribution of words with a certain number of phonemes as found in the U-lists is representative of the occurrence of words with a certain number of phonemes in Dutch.
There appears to be a considerable difference between the frequency of occurrence of phonemes in the U-lists and the phoneme distribution in normal language use. However, these results should be viewed with reservation on account of the absence of a representative phoneme frequency count for Dutch.
As a first attempt at finding out whether the words occurring in the U-lists can be regarded as representative of normal language use, we compared the distribution of words in the U-lists over the frequency classes as given by Uit den Boogaart (p.467 ff) to the distribution of the Uit den Boogaart corpus over the same classes. It appears that the U-lists contain a larger number of words with a high frequency of occurrence than the Uit den Boogaart corpus. As we defined "normal language use" as the way in which the words of the Uit den Boogaart corpus are distributed over the frequency classes given in the E-list (p. 467 ff), we have to conclude that the distribution of the words occurring in the U-lists differs from normal language use. On the other hand, the large number of highly infrequent words occurring in the Uit den Boogaart corpus certainly calls for further investigation into the claim that this corpus represents "normal language use".
Finally, we should like to state our awareness of the fact that by limiting our analysis of the U-lists to the claims made with respect to the distribution of words with a certain number of phonemes and the phonetic balance, other interesting aspects - especially from a

phonetic point of view - such as the influence of certain combinations of phonemes and the acoustic make-up of phonemes on the perception of the test words were not taken into account. All things considered, the main conclusion that can be drawn from this analysis is that there is a definite need for a more standardized Dutch speech audiometry test.

However, the compilation of a standardized speech audiometry test - though significant in itself - is not the purpose of our study. In this context we should like to mention an investigation which has recently been started at the Department of Experimental Audiology of the University of Utrecht with the goal of gathering material for the compilation of a new Dutch speech audiometry test. In this investigation special attention will be paid to the interchangeability of the sublists (for the notion sublist see also section 2.2).

As stated before, our approach to speech audiometry is primarily of a phonetic nature.

During the past years the crucial influence of prosodic factors on the perception of speech by the normally hearing has been well established. There is, however, relatively little to be found in the literature about the influence of prosodic cues on the perception of speech by persons afflicted with a hearing deficiency. In the following three chapters experiments will be reported that were carried out in order to provide an answer to the question whether prosodic factors are of comparable influence on the speech decoding process of normally hearing and hearing-impaired listeners.

Chapter III

The influence of prosodic parameters: sentence accent

3.1. Introduction

In recent years the important role of prosodic cues in speech perception has been well-established. In their studies of prosodic factors, speech researchers have focused on normally hearing listeners (see chapter I). The question arises whether these factors contribute to a comparable extent to the listening strategy of the hearing-impaired. As stated before, we could find only few examples of studies concerning the influence of prosodic factors on the perception of speech by hearing-impaired listeners.
Although primarily concerned with information and its processing in speech-reading (i.e. lip-reading) Risberg and Agelfors (1978 a,b) and Risberg and Lubker (1978) do provide us with some information on the ability of hearing-impaired listeners to identify prosodic patterns. Based on their assumption that the foremost problem in information processing during visual perception consists in the difficulty to extract prosodic information, they carried out an experiment in which intensity and fundamental frequency operations were first extracted from the acoustic signal. Subjects were then tested in a speech-reading task with or without these two signals transmitted through headphones. As test material unknown sentences, word pairs with contrasting prosodic patterns and four-word sentences with emphasis placed on one of the words were used. Their results show a considerable increase in the percentage of correctly perceived items when speech-reading was supplemented by information about intensity and fundamental frequency variations but a very small improvement when only auditorily presented information about intensity deflections was added. They

therefore conclude that pitch variation (intonation) forms the most important supplementary information and suggest that a speech-reading aid should preferably transmit information about fundamental frequency variations in the acoustic speech signal. In this particular experiment no hard of hearing subjects were used. In an earlier study (Risberg and Agelfors, 1978b) hearing-impaired subjects did participate in the test, but we are not supplied with comparative data as to testscores of normally hearing vs. hearing-impaired subjects. In this context we should also like to refer to an investigation carried out by Breeuwer (1985), which focused on the extraction of those speech parameters from the speech signal that contain sufficient linguistic information to achieve speech perception in combination with speech-reading.

In a more recent experiment concerning frequency discrimination ability and speech perception carried out by Risberg (1983), hearing-impaired subjects were asked to identify the emphasized word in three-word sentences. The sentences only contained voiced sounds and were read in a continuous manner without too much stress on the emphasized word. In this way, the main cue was expected to be the fundamental frequency change in the emphasized word. The hearing-impaired subjects were patients taking part in a vocational rehabilitation programme. Their ages ranged from 18 to 60. They suffered from either a congenital or an acquired mild to total hearing loss. The results indicate that a good frequency discrimination ability in the low frequency region is necessary for the detection of fundamental frequency changes. However, as regards subjects with a congenital loss and poor frequency discrimination ability in the whole frequency range, Risberg suggests that in these cases the poor results on the emphasis test may also have a linguistic explanation, i.e. these subjects have apparently never learnt the linguistic meaning of word emphasis.

Stark (1979) gives results of tests designed to assess prosodic feature reception in hearing-impaired children.

These results show that whereas hearing-impaired children had great difficulties in detecting differences in stress placement (e.g. whether stress occurred early or late in the sentence) they did not experience difficulties in managing purely temporal differences. In this context we should like to briefly mention two studies carried out to investigate the influence of speech rate - another important prosodic cue - on the perception of normally hearing and hearing-impaired listeners: Luterman, Welsh and Melrose (1966) and Spitzer and Osborne (1980). The influence of speech rate on the perception of normally hearing and hearing-impaired listeners will be dealt with in greater detail in chapter V.

Wingfield, Lombardi and Sokol (1984) advocate further research into the role of prosodic factors in speech reception, as results of research of this kind may prove to be relevant to "a better understanding of the useful perceptual abilities of persons with a hearing-impairment as well as those of elderly subjects who may have added difficulties with more central processing" (p. 133). According to Wingfield et al. prosody adds redundancy to the signal, a factor which becomes most important under difficult listening conditions.

In this chapter we will describe an experiment carried out in an endeavour to provide an answer to the question whether - on the sentence level - accent influences the speech decoding process of normally hearing and hearing-impaired listeners in a comparable manner. The variables investigated are accented vs. unaccented words, position of sentence accent (i.e. accented word) and sex of the speaker.

3.2. Method

3.2.1. Test material

3.2.1.1. Why sentences?

In this section only the test material used in our experiment will be accounted for; for a review of the test material generally used for the purpose of speech audiometry the reader is referred to chapters I and II. Our test material consisted of a series of unrelated sentences.
As far as the use of sentences is concerned it seems appropriate to briefly recall some of the arguments put forward to advocate the use of sentences in speech audiometric tests. Bench and Bamford (1979) fervently plead for preferring sentences over words in speech audiometric tests. They mainly derive their arguments from the simple fact that "because sentences are more than mere strings of words, perception of words in isolation is not necessarily a good predictor of the perception of sentences, which constitute the material of everyday speech" (p. 17). An additional advantage of sentences over words, pointed out by Speaks and Jerger (1965) is that they also allow investigation of the time domain, since they are of sufficient duration to permit alteration of the temporal characteristics of speech and their effects on successful perception. The same holds of course for various other prosodic parameters. In a recent article on the difficulties involved in estimating auditory handicap, Ward (1983) suggests an audiometric test consisting of "sentences taken from real life, spoken by males and females of different ages, in a variety of masking noises" (p. 318).
On the strength of arguments of the above-mentioned kind we decided that our test material should consist of sentences. For the construction of the test sentences

the following criteria were kept in mind. The sentences should syntactically be relatively simple, more or less equal in length so as not to be a burden on memory, and, of course, they should be semantically acceptable. Seventeen sentences (see Appendix B) of approximately equal length, viz. ten syllables were constructed. A panel consisting of ten native speakers of Dutch was asked to judge the sentences as to acceptability of the position of the sentence accent and overall level of semantic complexity. Only those positions that were accepted in minimally 75% of the cases were used for the experiment. As far as level of semantic complexity was concerned, nearly all members judged the sentences to be roughly equivalent. The frequencies of occurrence of the words used were looked up in the Uit den Boogaart (1975) word frequency count (cf. also Chapter II, section 3.2), which gives separate numbers for occurrence in written language and spoken language. We limited ourselves to the spoken language data.

As to the number of sentences used, we should like to remark the following. Any test list should in principle provide us with a convenient and reliable measure of subjects' hearing ability under specified conditions. By convenient and reliable we are referring to the problem of finding an acceptable balance between list length and list reliability: as list length is increased, the reliability of the scores obtained increases, this however, at the expense of increased test duration. Increasing the list beyond a certain point does not increase (and may even decrease) its reliability, since other factors such as fatigue begin to intrude. Lyregaard (1973) has expressed the relationship between accuracy of the scores obtained and list length mathematically; let it suffice here to touch upon the general nature of the problem. On the basis of various trial runs we finally decided that 17 sentences would achieve an acceptable balance between reliability and test duration. This is in accordance with Bench and Bamford (1979), who decided on 16 sentences as a suitable number of items per list on the basis of similar arguments.

3.2.1.2. Recording of the test sentences

In speech audiometric tests it is undoubtedly of great importance to choose the speaker(s) carefully. We selected our speakers - one male and one female - on the grounds of good intonation, clear articulation and good voice quality. Both were native speakers of Dutch, trained phoneticians and both are considered to speak standard Dutch. The speakers were instructed to make one pitch accent on the words underlined (see Appendix B). Each sentence was recorded in three versions, the difference consisting in sentence accent assignment: the accent could occur in three different positions in the sentence, viz. early, middle or late (see also Appendix B). Recordings were made in a sound-treated booth using high-quality equipment.
Every sentence was preceded by its number in order to alert the listener to the presentation of the next sentence. There was an interval of one second between the cessation of the item number and the start of the sentence. The interval between the end of each sentence and the onset of the next item number was 25 seconds, generally allowing ample time for the listener to respond (in writing).
In order to prevent ceiling effects in the case of the normally hearing listeners, we decided to mask our stimulus material with noise. The type of noise used was USASI, which has its most intense components within the frequency region of 50 - 1000 Hz, thus overlapping to a great extent with that frequency region which is most important for the perception of speech. Moreover, USASI noise as a function of the average intensity per sentence appeared to be the nearest equivalent to noise with the long-term average spectrum of speech which, at the time, was not available (see also Plomp and Mimpen, 1979). The average intensity was calculated by

determining the R.M.S value of the samples (for sampling procedure see Van den Berg, 1980) on the basis of its DC-voltage according to the formula:

$$V = \sum_{i=1}^{n} (X)_i^2 - n(\overline{X})^2$$

For the purpose of finding an S/N ratio that would yield approximately 50% correct responses, a critical value in speech intelligibility tests (see Plomp, 1978), a pilot experiment was performed (see Vingerling and Gil-Günzburger, 1980). On the basis of the results of this experiment, the S/N ratio was decided to be -2 dB for normally hearing and +5 dB for hearing-impaired subjects.

3.2.2. Subjects and presentation of the tests

In all, 106 subjects participated in the test; 53 of them were pupils of various secondary schools for hearing-impaired children; their ages ranged from 12 to 17 years and they suffered from a congenital hearing loss. Hearing-impaired subjects took the test individually. The 53 normally hearing subjects were both first-year students of the Department of English at Utrecht University and students of the Dutch school for Tourism and Recreation at Breda; they had no self-reported hearing-deficiencies. They took the test in a language laboratory equipped with headphones. Subjects of each group were randomly assigned to an experimental condition (male or female speaker, early middle or late sentence accent), which resulted in minimally 8 and maximally 12 subjects per condition. Both normally hearing and hearing-impaired subjects received oral and written instructions and were asked to listen to the test tape and write down after every test item whatever they heard. Subjects took part on a voluntary basis and were not paid for their services.

3.3. Analysis and results

3.3.1. Introduction

The way in which speech audiometry tests are scored affects the shape of the resulting speech intelligibility curves. Word lists are usually scored per phoneme, but to score sentence lists per phoneme would not only be too tedious and lengthy a task but would also run counter to the arguments which underlie the use of sentences for speech audiometry: their face validity as samples of everyday speech material, their "naturalness" and the opportunity they afford the listener to take advantage not only of phonotactic and morphological but also of syntactic and semantic constraints. For these reasons we regard scoring our sentence test per word as a reasonable alternative.
The first two sentences were practice items and were not incorporated in the analysis of results. The results were analysed as to the influence of accent (accented vs. unaccented words), position of accent in the sentence (early, middle or late) and sex of the speaker on correct word recognition. A comparison of pure tone audiograms of hearing-impaired subjects with their testscores was also performed.

3.3.2. Presence of accent, position of accented word and sex of the speaker

A breakdown of means and 2, 3 and 4-way analyses of variance were carried out for each experimental condition with percentage of correctly perceived words per sentence as criterion variable. The analyses of variance were supported by a Multiple Classification Analysis (Nie, Hadlai Hull, Jenkins, Steinbrenner and Bent, 1975). The results of the breakdown procedure are given in table 3.1 and graphically represented in figure 3.1.

The analysis of variance yielded three main effects, viz. presence of accent: $F(1) = 34.06$ ($p<.001$), position of accent: $F(1,2) = 11.85$ ($p<.001$) and subject category: $F(1) = 7.53$ ($p<.007$). Two-way interactions are strongest for subject category x position of accent: $F(1,2) = 17.91$ ($p<.001$) followed by position of accent x presence of accent: $F(1,2) = 5.08$ ($p<.007$). There is only one significant three-way interaction, viz. category of subject x speaker x position of accent: $F(1,2) = 3.23$ ($p<.05$).

Although S/N ratios for normally hearing and hearing-impaired subjects had been based on pilot experiments carried out in order to find an S/N ratio that would yield approximately 50% correct responses, the scores of both normally hearing and hearing-impaired subjects failed to reach the target level of 50% correct responses. Therefore, results do not warrant an interpopulation comparison as to absolute values of test results, but they do nevertheless allow us to make the following observations:

- accented words are perceived better than unaccented words; this holds for both subject groups, both speakers and all accent positions.
- hearing-impaired listeners score highest on the early accent position and lowest on the late accent position whereas normally hearing subjects appear to score highest on the middle accent position.

Table 3.1.: Mean percentage correctly perceived words and standard deviations (over 15 sentences) per accent position and per speaker for normally hearing (NH) and hearing-impaired (HI) subjects.

subjects	speaker	position of accent	presence of accent	mean	SD
HI, n= 9	male	early	-	35	22
			+	50	23
HI, n= 12	male	middle	-	27	25
			+	42	26
HI, n= 8	male	late	-	16	7
			+	19	9
HI, n= 8	female	early	-	26	24
			+	46	31
HI, n= 8	female	middle	-	21	19
			+	37	30
HI, n= 9	female	late	-	32	17
			+	33	20
NH, n=12	male	early	-	5	2
			+	15	11
NH, n= 9	male	middle	-	29	9
			+	54	10
NH, n= 8	male	late	-	17	7
			+	21	8
NH, n= 8	female	early	-	11	8
			+	35	15
NH, n= 8	female	middle	-	28	6
			+	56	10
NH, n= 8	female	late	-	22	5
			+	27	5

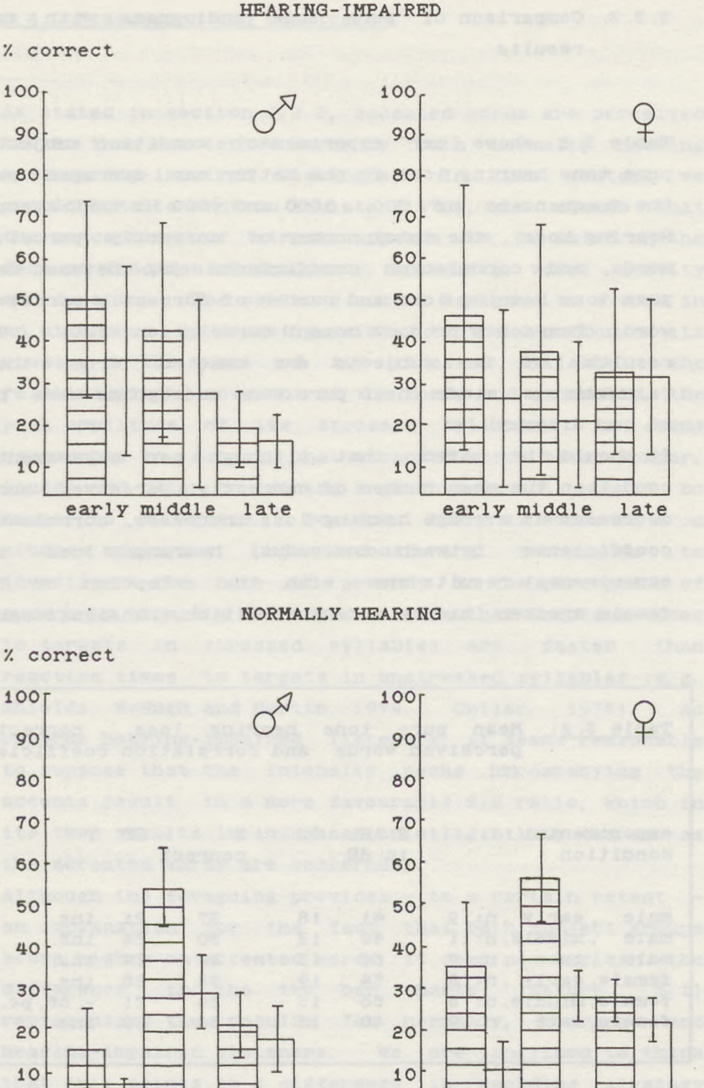


Figure 3.1: Mean percentage of correctly perceived words and standard deviations per accent position and per speaker; for normally hearing and hearing-impaired subjects

accented words unaccented words

3.3.3. Comparison of pure tone audiograms with test results

Table 3.2 shows per experimental condition subjects' pure tone hearing loss in the better ear averaged over the frequencies of 500, 1000 and 2000 Hz (AHL=Average Hearing Loss), the total number of correctly perceived words, and correlation coefficients (r) between mean pure tone hearing loss and number of correctly perceived words (Pearson's product moment correlation test). The results of two subjects are omitted from these calculations, since their pure tone audiograms were not at our disposal.
It should be noted, that although per experimental condition the mean number of correctly perceived words decreases as average hearing loss increases, correlation coefficients between individual hearing loss and experimental results are - with the exception of the female speaker middle accent condition - insignificant.

Table 3.2: Mean pure tone hearing loss, correctly perceived words and correlation coefficient (r).

experimental condition	$\bar{x}$ AHL in dB	SD	$\bar{x}$ correct	SD	r
male , early , n= 9	41	18	37	21	ins.
male , middle, n=11	49	13	30	24	ins.
male , late , n= 8	61	13	22	17	ins.
female, early , n= 8	54	19	33	26	ins.
female, middle, n= 8	68	13	24	21	-.86, $p<.01$
female, late , n= 9	40	12	36	19	ins.

3.4. Discussion and conclusion

As stated in section 3.3.2, accented words are perceived better than unaccented words by both normally hearing and hearing-impaired listeners. In this context we should like to mention Lehiste (1970), who states that the perception of stress appears to be based on the factors fundamental frequency, intensity, vowel quality and duration. The sentence accent assigned to a word in an utterance is directly related to the duration of its vowel (or the vowel of its stressed syllable), the relative pitch movement of the word, and generally, the peak amplitude of its stressed syllable. It seems reasonable to expect that accented words being longer, louder and often containing a pitch movement should be easier to recognize. Besides, there is evidence from studies employing phoneme-monitoring techniques to investigate the role of prosody in the perception of speech by normally hearing listeners that reaction times to targets in stressed syllables are faster than reaction times to targets in unstressed syllables (e.g. Shields, McHugh and Martin, 1974; Cutler, 1976). As regards hearing-impaired listeners, it seems reasonable to suppose that the intensity peaks accompanying the accents result in a more favourable S/N ratio, which in its turn results in increased intelligibility (as far as the accented words are concerned).

Although the foregoing provides - to a certain extent - an explanation for the fact that both subject groups score higher on accented words, it does not explain the difference in the two bar charts (figure 3.1) representing the results for normally hearing and hearing-impaired listeners. We are inclined to think that this points to a difference in recoding strategy between normally hearing and hearing-impaired listeners and we will offer some tentative explanations for this observation.

In the case of the normally hearing listeners the marked peak in the middle accent position may be explained by the fact that the listeners made use of the prosodic information provided by the preceding intonation contour, in order to locate the accented word and thus facilitate its recognition. This explanation is based on evidence from studies by Cutler (cf. Cutler, 1976; Cutler and Foss, 1977; Cutler and Norris, 1979; Cutler and Darwin, 1981), who comes to the conclusion that listeners use their knowledge of (preceding) prosody to focus their attention on accented words in order to facilitate the ongoing process of sentence understanding. To this purpose various sources of prosodic information can be used such as F0 variation and durational cues. However, if we accept the above-mentioned as an explanation for the peak in the middle accent position the question why this should not hold for the late accent position as well remains unanswered.

In an endeavour to answer this question, we analysed the different sentence accents (early, middle and late) as realised by the speakers in terms of pitch patterns (see also Vingerling, 1983). Schematically represented the results were as follows:

	speaker	
accent position	♀ pitch pattern	♂
early	fall	rise+fall
middle	rise+fall/fall	rise+fall
late	rise+fall/fall	rise+fall/fall/rise

Pitch patterns are ordered according to frequency of occurrence in the stimulus material. It appeared that the late accent position showed the largest variety in pitch patterns, viz. ordered according to frequency of occurrence: rise+fall; fall; rise. By "rise+fall" is meant a fast rise immediately followed by a fast fall both within the same syllable (cf. Collier, 1972; Van Geel, 1983). Moreover the fall pattern appeared to be less common than both the rise and the rise+fall pattern when compared with data concerning frequency of occurrence of Dutch pitch patterns, given in Collier (1972), viz. rise+fall 33,2%; rise 3,9% and fall 1,9%.

1) The difference in overall percentage of correct responses, which appeared to be somewhat higher in the female speaker condition (31% vs. 27%) may be explained by the fact that the use of less common pitch patterns does not meet with the expectations of the listeners and thus has a negative influence on successful perception (cf. 't Hart, 1981).
2) Accepting the - speculative - idea that a rise+fall is perceptually more salient than a single rise or fall, the peak in the scores for the middle accent position may be explained by the fact that both speakers for the greater part used the rise+fall pattern in that case.

The results for the hearing-impaired listeners yield a completely different picture. The scores are highest for the early accent position and appear to become lower across accent positions. An analysis of the fundamental frequency variations and the coinciding peaks in the intensity curve as found in the late accent version of the test sentences is reported on in Vingerling (1983). This analysis showed that in 73% of the total number of cases the intensity of the peak accompanying the late accent position fell - on average - 5 dB short of the level of the intensity peaks accompanying the early and middle accent positions. Besides, the overall intensity curve appeared to decline towards the end of the sentence, which is not surprising as the subglottal pressure is highest at the beginning of the sentence and gradually becomes lower. In this context Lehiste (1970) and Van Katwijk (1974) should be mentioned, who - for English and Dutch respectively - consider intensity to provide a cue for the presence of stress, though much weaker than the cues as provided by fundamental frequency and duration. Moreover reduced intensity results in a less favourable S/N ratio, which in its turn influences intelligibility. Results given in Vingerling (1983) show that the intelligibility scores for words that occurred in both middle and late accent position (in different sentences) appeared to be considerably lower in the case of the late accent position. A closer analysis of the sentences concerned showed that there was no reason to suppose that differences concerning semantic or syntactic constraints could have caused the intelligibility scores to be different. Consequently, these results seem to indicate that towards the end of the sentence the decline in intensity results in a less favourable S/N ratio and therefore reduced intelligibility.

Overall percentage of correct responses appeared to be slightly higher in the female speaker condition than in the male speaker condition (31% vs. 27%). Apart from the non-representativeness of having only one speaker per sex, an attempt at generalizing the above findings would not be warranted for the following two reasons:

1) The frequent use of the fall pattern (the least common Dutch pitch pattern, cf. Collier, 1972) by the male speaker, which may have had a negative influence on perception.
2) Calculating the average intensity per sentence (see also section 2.1.2) we noticed that the overall duration of the sentences spoken by the female speaker was longer than the overall duration of the sentences spoken by the male speaker. As it is generally assumed that slowing down the rate of speech will improve intelligibility, the fact that the speech rate of our female speaker was slower than that of the male speaker might explain the difference in scores. The influence of speech rate on the perception of normally hearing and hearing-impaired listeners will be dealt with in chapter V.

As regards the high standard deviations (see figure 3.1 and table 3.1) in the scores of the hearing-impaired listeners the following can be said. Since the only prerequisite for participation in our test was that listeners should suffer from a congenital hearing loss, the results have been influenced by individual differences in hearing acuity among listeners resulting in a large variability of the scores obtained.

As to the comparison of pure tone audiograms with test results, our data do not provide evidence for the validity of pure tone testing as a generally applicable tool to estimate a variety of hearing-impaired listeners' ability to understand everyday speech.

On the whole we feel justified to draw the tentative conclusion that prosodic knowledge such as concerning F0 variations plays a role in sentence processing as far as normally hearing listeners are concerned. The hearing-impaired listeners also seem to follow a strategy which, however, is completely different: they score highest when the sentence accent occurs in the beginning of the sentence. Lack of prior context and possibilities to focus attention on the accented word do not seem to make any difference. Intensity seems to provide the strongest cue; the scores become lower as overall intensity declines. Prosodic knowledge and linguistic expectations (such as concerning frequency of occurrence of pitch patterns) prove to be of less importance. The results of the experiment reported on here seem to indicate that the generally acknowledged influence of prosodic factors - among them accent - on the perception of speech by the normally hearing appears to be less clear in the case of the hearing-impaired who seem to follow a different listening strategy, as prompted by their handicap.

Chapter IV

The influence of prosodic parameters: pitch contours

4.1. Introduction

As stated in chapter I, our investigation is concerned with the influence of prosodic factors on the perception of speech by normally hearing and hearing-impaired listeners. As prosodic factors which might show a different contribution to perception for these two groups of listeners accent, pitch contours and speech rate were chosen. In the previous chapter we dealt with accent (as opposed to stress). By accent we understand sentence accent, which means that - for each sentence - our speakers had been instructed to make one pitch accent on the word underlined. Words to receive sentence accent could occur in three different positions in the sentence, viz. early, middle or late. In this chapter we will describe an experiment carried out to investigate the role of pitch contours in the perception of speech (i.e. sentences) by normally hearing and hearing-impaired listeners. By pitch contours we understand the overall pitch contours constituting the intonation of sentences. Before describing the experiment, we shall briefly discuss the notion pitch and the different angles from which pitch phenomena can be approached.

The voice pitch of a speaker is what we hear as the melody or intonation in a person's speech. The sensation of pitch results from the periodic vibrations of the vocal cords; there is a close correlation between the rate of vocal cord vibrations (fundamental frequency) and what we perceive as voice pitch. Reviewing studies concerned with pitch phenomena we can generally distinguish between two different kinds of approach: the linguistic approach and the perceptual approach. Linguistic descriptions of pitch usually concentrate on the functions of pitch phenomena (intonation) within the context of sentences such as e.g. distinguishing questions from statements and disambiguating semantic and syntactic ambiguities. In perceptually oriented studies of pitch phenomena the emphasis lies on the perceptual relevance of pitch movements. An example of a perceptual approach to the study of intonation is the work carried out at the Institute of Perception Research, Eindhoven (cf. e.g. Cohen and 't Hart, 1967; 't Hart and Cohen, 1973; 't Hart and Collier, 1975; Collier and 't Hart, 1981). These studies have all concentrated on the perceptual relevance of pitch movements and do not account for their linguistic function. As far as our study is concerned it goes without saying that as our main interest is the perceptual domain, to which pitch phenomena obviously belong, the approach to be adopted here should be of a perceptual nature. As our experiment is concerned with possible differences between the role of pitch contours in the perception of speech by normally hearing and hearing-impaired listeners, we should like to mention some experimental findings concerning the use of information contained in pitch contours in applications for hearing-impaired - and deaf - persons. One of these applications is the use of prosodic information provided by pitch contours in combination with lipreading. Experiments carried out by Rosen, Moore and Fourcin (1980) and Rosen, Fourcin and Moore (1981) demonstrated that pitch information - presented auditorily - can be an enormous help in lip-reading. In these experiments pitch information appeared to be an essential complement to the visual information already available on the face. Rosen and Fourcin (1983) claim that although the role of prosodic information provided by pitch contours is often ignored when evaluating the sensory abilities of the hearing-impaired, this information is essential especially in combination with lip-reading as it is invisible. Apart from being an important aid to lip-reading, pitch information is also used in cochlear stimulation (cf. Howard and Fourcin, 1983). The subject of cochlear implants (cf. Risberg, 1982, for an overview of research in this field) will be dealt with in more detail in chapter VI, section 6.4.

As has been stated above, the experiment to be described here was carried out to investigate the role of pitch contours in the perception of speech by normally hearing and hearing-impaired listeners with special emphasis on the question whether the prosodic information provided by the pitch contour of a sentence contributes differentially for these two groups of listeners to its intelligibility. The variables investigated are normally intonated vs. monotonized sentences and sex of the speaker.

4.2. Method

4.2.1. Introduction

As we have already described in section 4.1 our study focuses on three prosodic factors, viz. accent, pitch contours and speech rate. Each of these factors is investigated in a separate experiment; the experiment dealing with accent has been described in chapter III. For practical reasons we decided to offer the stimulus material to be used in the pitch contour and speech rate (see next chapter) experiments simultaneously, i.e. we constructed a test which contained both sets of stimuli. In all, the stimulus material consisted of 25 sentences (see Appendix C) selected from the corpus as described by Plomp and Mimpen (1979), 10 of which were used for the intonation experiment and 15 for the speech rate experiment (see also Appendix C). The Plomp and Mimpen corpus consists of sentences that have been constructed with the following criteria in mind:

- the sentences were selected in such a way as to approach an everyday speech situation as closely as possible.

- the length of the sentences was more or less the same in all cases, viz. 8 or 9 syllables so that they could be repeated easily without causing memory strain.
- the intelligibility of the sentences had been tested thoroughly so that the chances of their being correctly perceived - when presented in noise - by a large group of normally hearing listeners were about equal.
- the frequencies of occurrence of the various phonemes were approximately equal for all sublists.

As regards our test sentences, since they were a subset of the original material, we checked again whether the phonemes were equally distributed over the sentences. For the composition of our test the reader is referred to Appendices D (for hearing-impaired listeners) and E (for normally hearing listeners). The fact that in the case of the hearing-impaired listeners only one test sufficed whereas in the case of the normally hearing listeners eight different tests were constructed is a result of the difficulties we experienced in finding an adequate number of hearing-impaired subjects prepared to participate in our experiments. We shall return to this matter later on.

4.2.2. Recording and processing of the test sentences

For reasons of comparison we decided to choose the same speakers as in our previous experiment i.e. one male and one female, both native speakers of Dutch, trained phoneticians and generally considered to speak standard Dutch. Recordings were made in a sound-treated booth, using high-quality equipment.
As we wanted to investigate the possibly differential role of pitch contours in the decoding of speech by normally hearing and hearing-impaired listeners, we decided to offer our stimulus material in two versions, namely monotonized vs. intonated. For this purpose the

sentences were further processed by means of LPC analysis. This means that the input signal (the original speech signal) was low pass filtered with a cut-off frequency of 5 kHz, digitized with a sample frequency of 10 kHz and written onto disc with a resolution of 12 bits per sample. The LPC analysis involved calculating - in 10 ms steps - 10 filter coefficients describing the spectral envelope, the amplitude and the voiced-unvoiced (VUV) parameter of the 25 ms speech segment at issue. Consequently, each step yielded a set of 13 figures or "frame"; 100 frames per second of speech. Besides, the fundamental frequency (F0) was measured and added to the frames in a separate programme. After the analysis all sentences were interactively corrected - if necessary - for mistakes in both F0 and voiced-unvoiced parameter (VUV). Finally, the monotonized version was produced by resynthesizing the sentences with a fundamental frequency fixed at a constant level of 100 Hz for the male speaker and 200 Hz for the female speaker. In order to exclude differences in quality between the two versions, the intonated sentences were resynthesized while preserving the original fundamental frequency.

Since we are interested in the degree of auditory handicap in an everyday communication situation, we decided to present our sentences mixed with interfering noise. Moreover, the use of masking noise enables us to prevent ceiling effects in the case of normally hearing listeners. As the sound of one or more competing speakers may be considered to represent the main source of interference in everyday listening situations, noise with the long term average spectrum of speech was adopted as standard noise. In this case the spectrum of the noise corresponded with the average of the speech spectra of both speakers. No systematic individual differences could be detected.

The average intensity per sentence was calculated by means of a computer programme developed by Van den Berg (1980). In order to find an S/N ratio that would yield approximately 50% correct responses, a critical value in speech intelligibility tests (see Plomp, 1978), pilot experiments were performed. On the basis of the results of these experiments and for the sake of comparability the S/N ratio was decided to be the same for both conditions, i.e. monotonized and intonated: +10 dB for hearing-impaired listeners and -1 dB for normally hearing listeners. Both speech signal and noise were mixed onto one track of a two-track taperecorder, preserving the proper S/N ratio. Loudness was set at a comfortable level.

Every sentence was preceded by its number in order to alert the listener to the presentation of the next sentence. The interval between the end of each sentence and the onset of the next item number was 15 seconds, generally allowing sufficient time for the listener to respond in writing. We decided on an interval of 15 seconds as the 25 seconds' interval used in our first experiment (cf. chapter III, section 3.2.1.2) appeared to lengthen the duration of the test unnecessarily. The whole set of 10 test sentences (for the intonation experiment) had been divided into 5 monotonized and 5 intonated sentences. In both cases (i.e. monotonized and intonated) three sentences were spoken by the female speaker and two by the male speaker (cf. also Appendix C). The test was preceded by practice items.

4.2.3. Subjects and presentation of the test

In all, 170 subjects participated in the test: 40 hearing-impaired and 130 normally hearing. The 40 hearing-impaired subjects were pupils from various schools for hearing-impaired children, their ages ranging from 10 to 17 years. They all suffered from a congenital hearing loss of maximally 60 dB for the better ear. We decided to choose children with a congenital hearing loss in order to exclude possible differences in vocabulary (among our subjects) due to the onset of handicap. The 130 normally hearing listeners were pupils from the fifth and the sixth forms of various primary schools, their ages ranging from 10 to 12 years. They had no self-reported hearing deficiencies. The age-group to which our normally hearing subjects belonged was chosen on the basis of the results of an enquiry among speech therapists and teachers of schools for hearing-impaired children. They were unanimous in judging that due to the difference in tempo of intellectual development between normally hearing and hearing-impaired children (as a result of the handicap of the latter) this age-group was more or less comparable to our hearing-impaired subjects. All subjects took the test individually. They received oral and written instructions in which they were asked to write down what they heard after every sentence, even if this amounted only to fragments.

4.3. Analysis and results

4.3.1. Monotonized vs. intonated

For reasons given in chapter III, section 3.3.1, we decided to score our sentence test per correctly recognized word. The 2 initial practice items were not incorporated in the analysis of results. Tables 4.1 and 4.2 give the results for normally hearing and hearing-impaired listeners per condition (monotonized vs. intonated) and per speaker (male vs. female).

Table 4.1: Mean percentage correctly perceived words and standard deviations (in %) per condition, per speaker and pooled for male and female speaker; for normally hearing listeners (n=130).

	correct in %		correct in %		correct in %	
	♀		♂		both speakers	
condition	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
monotonized	11	15	11	13	11	14
intonated	19	18	20	18	20	18

Table 4.2: Mean percentage correctly perceived words and standard deviations (in %) per condition, per speaker and pooled for male and female speaker; for hearing-impaired listeners (n=40).

	correct in %		correct in %		correct in %	
	♀		♂		both speakers	
condition	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
monotonized	52	29	53	32	53	31
intonated	60	35	72	34	66	35

Tables 4.1 and 4.2 show that normally intonated sentences are perceived better than monotonized sentences; this holds for both groups of listeners:

- normally hearing listeners: $F(1,9)= 35.16$ $(p<.0002)$
- hearing-impaired listeners: $F(1)= 11.25$ $(p<.001)$

The effect of speaker variation is insignificant in both cases. As regards the results in the case of hearing-impaired listeners, it should be noted that sentence 1 of the intonated sentences (cf. Appendix C) was not included in the analysis of results. Hearing-impaired subjects appeared to score significantly lower on this sentence than they did on the other four: $F(4,195) = 11.84$ ($p<.05$). Close examination showed this sentence to be highly improbable from a semantic point of view.

4.4. Discussion and conclusion

The results of this experiment indicate that the overall pitch contour of a sentence contributes to its intelligibility as normally intonated sentences are perceived better than monotonized sentences. On the basis of these results we are inclined to believe that the role played by pitch contours in the perception of speech by normally hearing vs. hearing-impaired listeners is of a similar nature. This is in accordance with our expectations based on experimental evidence found in studies concerning - in the case of normally hearing listeners - the communicative function of pitch contours (cf. for Dutch: Van Katwijk, 1974; Nooteboom, Brokx and De Rooij, 1978; Brokx, 1979) and - in the case of hearing-impaired listeners - the use of pitch information as an aid to lip-reading or in cochlear stimulation (for references see section 4.1 and chapter VI).
Although pitch contours appear to affect the perception of speech by normally hearing and hearing-impaired listeners in a similar way, we do observe a striking difference in overall level of scores (expressed in mean percentage of correctly perceived words) between our two groups of listeners. In spite of the fact that the S/N ratios used in this experiment, viz. -1 dB for normally hearing and +10 dB for hearing-impaired listeners, had been based on pilot experiments (cf. section 4.2.2) the

scores of the normally hearing listeners failed to reach the target level of 50% correct responses by a long way. A possible explanation for this may be found in the combination of "speech noise" (i.e. noise with the long term average spectrum of speech) and "LPC speech" (i.e. speech generated by means of LPC analysis). In a chapter on the perceptual evaluation of synthetic speech generated by an analysis-resynthesis system (LPC), Vogten (1983, p. 124) states that the fact that the rest signal of the analysis is replaced by periodic impulses, white noise or silence means that much information present in the original signal (i.e. natural speech) is lost. He goes on to say that although as far as connected speech is concerned this loss is often admissible, it may have a negative influence when the demands made on the system are higher. Within the context of our study this could mean that the fact that our sentences generated by means of LPC analysis were presented under adverse listening conditions (i.e. masked with noise) may have influenced the scores negatively. In this connection we should also like to mention results given by Van Loon (1984), who found when comparing the intelligibility of natural speech and LPC speech, both presented mixed with interfering noise, that the intelligibility scores obtained with natural speech were considerably higher. With regard to the large variability of the test scores, the following can be said. Although our test sentences had been developed to satisfy a number of criteria (cf. section 4.2.1), the possibility of the results being dependent on the sentences used appears not to have been excluded. With due allowance for the time that has been spent developing test material meeting a variety of criteria in order to improve test reliability (cf. e.g. Noble, 1978; Bench and Bamford, 1979; Garstecki, 1980), we should like to emphasize - once more - the importance of such efforts. Apart from variability due to the test material used, possible individual differences in hearing acuity among our subjects should also be mentioned to account for the high standard deviations found in the case of the hearing-impaired listeners compared with those found for the normally hearing listeners (cf. also chapter III, section 3.4). Finally, as far as speaker variation is concerned, the results of our experiment indicate that this variable is of relatively little influence. A comparison of the mean percentages of correctly perceived words per speaker, for both conditions and both groups of listeners, shows that the differences are small in nearly all cases. The results as found in the intonated condition, for hearing-impaired listeners, are the only exceptions.

[illegible]

information present in the original natural speech is lost. He goes on to say that although as far as connected speech is concerned this loss is often admissible, it may have a negative influence when the demands made on the system are higher. Within the context of our study this could mean that the fact that our sentences generated by means of LPC analysis were presented under adverse listening conditions (i.e. masked with noise) may have influenced the scores negatively. In this connection we should also like to mention results given by Van Leeuwen (1984), who found when comparing the intelligibility of natural speech and LPC speech, both presented mixed with interfering noise, that the intelligibility scores obtained with natural speech were considerably higher. With regard to the large variability of the test scores, the following can be said. Although much test material has been developed to satisfy a number of criteria (cf. section 4.2.4), the possibility of the results being dependent on the sentences used appears not to have been excluded. With due allowance for the time that has been spent developing test material meeting a variety of criteria in order to improve test reliability (e.g. [illegible], 1986; Plomp and Mimpen, 1979; Hagerman, 1982), we should like to emphasize once more the importance of such effects. Apart from variability due to the test material used, possible individual differences in hearing acuity among our subjects could also be mentioned to account for the high standard

Chapter V

The influence of prosodic parameters: speech rate.

5.1. Introduction

This chapter is the last one in a series of three chapters in which we report on the experiments performed as part of our investigation into the influence of prosody on the perception of speech by normally hearing and hearing-impaired listeners. In the previous chapters III and IV the prosodic factors accent and pitch contour have been dealt with; in this chapter we will be concerned with speech rate.
Speech rate is an important prosodic cue, the effect of which on intelligibility has not been investigated extensively. On the speech production level, several authors have reported on factors that could be responsible for differentiations in rate of speech (Goldman-Eisler, 1968; Grosjean and Deschamps, 1975; Grosjean and Lane, 1974; Grosjean, 1977; Butcher, 1981; Gay, 1981). The following factors are generally considered to be of importance for the assessment of speech rate: the number of pauses, articulation rate and the duration of pauses. However, as far as our study is concerned, we are not interested in the production of speech tempo but in its effect on (speech) perception. "Could you speak more slowly, please?" is a question often asked by a listener to indicate that he/she is unable to understand what the speaker is saying. Implicit in this question is the expectation that a decrease in the rate of presentation will improve intelligibility. In the experiments to be described here the intelligibility of sentences spoken at different speech rates was investigated in order to gain more insight into the influence of speech tempo on the perception of speech by normally hearing and hearing-impaired listeners. We hoped that the results

of these experiments would contribute to finding answers to the following two questions with respect to both of our listener populations:

1) Does increasing the rate of speech beyond a normal range affect intelligibility?
2) Does - as is commonly thought - slowing down the rate of speech improve intelligibility?

Before dealing with our experimental work, we will briefly review some studies concerning the influence of speech rate on intelligibility. In this context we should like to emphasize that we are not going to discuss the various methods employed in manipulating speech tempo. Let it suffice to say that by time-compression we understand accelerating and by time-expansion slowing down the rate of speech.

As regards normally hearing listeners Foulke and Sticht (1969) in a review of research on the intelligibility of accelerated speech come to the conclusion that when a certain critical word rate is reached (approximately 4.6 words per second) the loss in comprehension is no longer exclusively determined by signal degradation but also by speech rate. They suggest that the loss in comprehension may then also be explained by the fact that when the word rate is too high words cannot be processed as fast as they are received, which results in a loss of speech information. Van Balen (1980) in a study of the effects of speech rate on the intelligibility of speech segments and excerpts concludes that the intelligibility of fragments with comparable duration is not influenced by differences in rate of speech provided that speech rates do not exceed 7.6 syllables per second after which rate effects begin to manifest themselves. Apart from the rate of presentation there are also other factors which, combined with an increase in speech rate, appear to affect intelligibility.

Age appears to have a significant influence on discrimination scores for rate-altered speech (cf. Schon, 1970; Konkle, Beasley and Bess, 1977). Results of investigations of the intelligibility of rate-altered speech reported by Riensche, Lawson, Beasley and Smith (1979) show that young adults maintained maximum intelligibility scores up to 30% time-compression, whereas older adults achieved maximum intelligibility scores when the time structure was normal, i.e. for them time-compression/expansion invariably resulted in reduced intelligibility. These results appear to correspond well with preferred listening rates for speech of 15% compression for young adults and near normal rates for older adults as found by Riensche et al. (1979). From a clinical viewpoint these results fail to support the common practice of slowing down speech rate when communicating with the older and especially the hard-of-hearing adult.

As far as hearing-impaired listeners are concerned, it is often assumed in clinical practice that slowing down the rate of speech will improve intelligibility. Besides, there have been various studies of the effect of time-compression and expansion of speech to investigate the possibility of a degrading effect associated with various kinds of hearing loss (cf. Spitzer and Osborne, 1980). According to Luterman, Welsh and Melrose (1966) there appear to be no differential effects of time-compression upon the intelligibility of normally hearing subjects and patients having conductive or sensorineural hearing losses. Sticht and Gray (1969) found that the discrimination of time-compressed words was not affected differentially by the nature of a subject's hearing ability, i.e. increasing the amount of time-compression affected the perceptual performance of both sensorineural and normal hearers in a similar way.

De Chiccis, Orchik and Tecca (1981) report a number of investigations of central auditory abilities involving normally hearing children and adults (Beasley, Schwimmer and Rintelmann, 1972; Beasley, Maki and Orchik, 1976) as well as adults with sensorineural hearing loss (Sticht and Gray, 1969; Kurdziel, Rintelmann and Beasley, 1975). In most of these investigations time-altered versions of standard speech discrimination tests are employed. De Chiccis et al. (1981) investigated the effects of time-compression on word intelligibility of two different word lists. It appeared that the results differed depending on the word list used. Besides, they compared the results of their investigation with data previously reported by Beasley et al. (1972) in an effort to examine the effect of talker on clinical measures of time-compressed speech discrimination. Although for both word lists the speech discrimination scores decreased with increasing time-compression, there was a significant difference in mean scores between the two lists at the 30% and 60% levels of time-compression. As to the effect of talker they come to the conclusion that this is a significant variable, especially at higher rates of time-compression (in this case 60%). On the basis of these results they conclude that although various studies have provided support for the use of time-compressed speech in the assessment of central auditory function, the data reported should not be generalized as they appear to differ depending on the test material used.

As has been stated above, the aim of the experiments to be reported on here was to investigate whether speech rate is of comparable influence on the speech decoding process of normally hearing and hearing-impaired listeners. For this, the intelligibility of sentences spoken at different speech rates by a male and a female speaker was investigated for normally hearing and hearing-impaired listeners.

5.2. Method

5.2.1. Recording and processing of the test sentences

The test material consisted of 15 sentences (for which see Appendix C), selected from the corpus as described by Plomp and Mimpen (1979). The decision that our test material should consist of sentences was taken for the following two reasons (for which see also chapter III, section 3.2.1). Firstly, the use of sentences of sufficient duration would enable us to investigate the influence of prosodic factors (in this case speech rate) on intelligibility. Secondly, sentences can be regarded as the material of everyday speech and as such are more representative of an everyday listening situation than e.g. isolated words.

The sentences were read out by two native speakers of Dutch: one male and one female, who had been instructed to speak at a rate they considered to be normal. The rate at which the sentences had been spoken was taken as a starting-point for further processing. By means of LPC the sentences were artificially expanded to 156% of the original duration (slow rate), and compressed to 64% of the original duration (fast rate). These two extremes were chosen based on the results of pilot experiments: a higher level of compression would cause the intelligibility scores to fall to an unacceptably low level and a higher level of expansion would cause the speech to sound very unnatural. Besides, 60% time-compression appears to be one of the conditions commonly used in clinical applications of time-compressed speech (cf. Beasley and Freeman, 1977) and allows us to compare the results obtained. Since mechanical expansion/compression of speech affects all components equally, and since we know that in natural decrease/increase in speech rate the constituting segments are affected differentially, the resulting 30 sentences were offered to the original speakers with the instruction to repeat them trying to keep as close as possible to the rate of speech of the sentences presented. This would result in more natural speech than mechanical rate alterations would yield. Table 5.1 gives the mean speech rates in syllables per second, per condition (LPC example vs. realized natural output) and per speaker.

Table 5.1:	Mean of speech rates (in syllables per second) per condition (LPC vs. realized) and per speaker.			
	♀		♂	
	LPC	realized	LPC	realized
slow	3.4	3.6	3.0	3.0
normal		5.4		4.7
fast	8.9	8.5	7.3	6.5

It can be seen from table I that the differences in rate of speech between the LPC example and the natural output realized by the two speakers were small with the exception of the female speaker, fast condition. As regards the expression of speech rate in (linguistic) syllables per second we are well aware that this is a questionable matter, which certainly deserves more attention. However, we shall not attempt to fully discuss the problems involved in defining speech rate in terms of number of syllables per time unit as we consider this to be beyond the scope of our investigation (for a discussion of this problem cf. e.g. Den Os, 1985). Per speaker 45 sentences were finally used for the test, i.e. 15 sentences in three different versions, viz. normal, slow and fast rate (see Appendix C). In order to avoid possible confusion we should like to emphasize once more that our test material consisted of natural speech, viz. the sentences repeated by our two speakers while trying to keep as close as possible to the rate of speech of the LPC examples.

In order to prevent ceiling effects in the case of the normally hearing listeners, their sentences were masked with noise. The type of noise used was speech noise, i.e. noise with a spectrum that corresponded with the average of the speech spectra of both speakers (cf. also chapter IV, section 4.2.2). Based on a pilot study the S/N ratio was set at -1 dB for normally hearing listeners and +7 dB for hearing-impaired listeners, aiming at a target level of approximately 50% correct responses for the normal rate.

5.2.2. Listeners

In all, 168 listeners participated in the test: 40 hearing-impaired and 128 normally hearing listeners. The hearing-impaired listeners were pupils from various secondary schools for hearing-impaired children, their ages ranging from 10 to 17 years. They all suffered from a congenital hearing loss of maximally 60 dB for the better ear. We decided to choose children with a congenital hearing loss in order to exclude possible differences in vocabulary (among our listeners) due to onset of the handicap. The 128 normally hearing listeners were pupils from the fifth and sixth forms of various primary schools, their ages ranging from 10 to 12 years. They had no self-reported hearing deficiencies. For further details on the choice of our listeners the reader is referred to section 4.2.3.

5.2.3. Listening procedure

All listeners took the test individually. They received oral and written instructions in which they were asked to write down what they heard after every sentence, even if this amounted only to fragments. Every sentence was preceded by its number in order to alert the listener to the presentation of the next sentence. The interval between the end of each sentence and the onset of the next item number was 15 seconds, generally allowing sufficient time for the listener to respond in writing (cf. also chapter IV, section 4.2.2). Each test (both for normally hearing and for hearing-impaired listeners) was preceded by practice items. Due to the fact that no large groups of hearing-impaired listeners were available, we had to construct two separate tests: a small scale test for hearing-impaired listeners and a large scale test for normally hearing listeners.

In the case of the hearing-impaired listeners only 15 out of the total number of 90 sentences (15 sentences x 3 rates x 2 speakers) were chosen for the listening test. Five sentences were selected for each speech rate of which two were spoken by the male speaker and three by the female speaker (see Appendix D).

We divided the 128 normally hearing listeners into 8 groups of 16 listeners. Each group listened to a different subset of 15 sentences out of the total 90 sentences. Each subset was composed in the same way as in the case of the hearing-impaired listeners (for an example the reader is referred to Appendix E).

5.3. Results

The results were analysed as to influence of speech rate and sex of the speaker. Tables 5.2 and 5.3 give the results per condition, i.e. normal, slow and fast rate, and per speaker for normally hearing and hearing-impaired listeners respectively. The results are expressed in mean number of correctly perceived words. In this context "correctly perceived" implies that spelling mistakes were not taken into account.

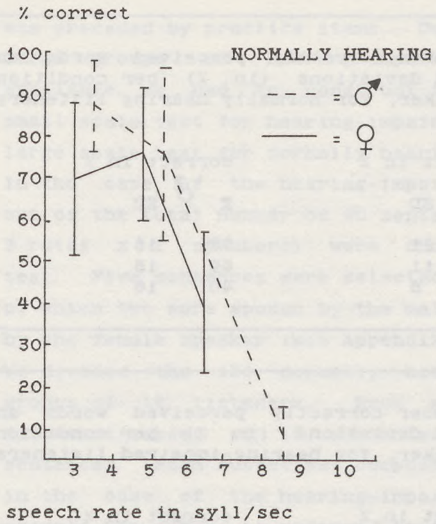
Table 5.2: Mean number correctly perceived words and standard deviations (in %) per condition, per speaker, for normally hearing listeners.

	correct in % ♀		correct in % ♂	
condition	$\bar{x}$	SD	$\bar{x}$	SD
normal	75	21	75	16
slow	87	11	69	18
fast	8	8	40	16

Table 5.3: Mean number correctly perceived words and standard deviations (in %) per condition, per speaker, for hearing-impaired listeners.

	correct in % ♀		correct in % ♂	
condition	$\bar{x}$	SD	$\bar{x}$	SD
normal	59	38	64	30
slow	63	35	59	30
fast	7	13	50	29

Figure 5.1 presents per speaker, for both groups of listeners, the mean percentage of correctly perceived words as a function of speech rate. Tables 5.2 and 5.3 as well as figure 5.1 show that the differences in scores (in mean % correctly perceived words) between the conditions normal and slow are small; this holds both for normally hearing and hearing-impaired listeners. Speaking at a fast rate appears to have dramatic consequences for both groups of listeners. Analyses of variance and post-hoc analyses (Scheffé) show that only one difference appeared to be significant for both speakers, viz. the difference between the conditions normal and slow vs. fast (with the exception of the female speaker, hearing-impaired listeners). Therefore, the point at which intelligibility begins to decline substantially lies between 6.5 and 8.5 syllables per second, which goes for both groups of listeners. Up to 6.5 syllables there is no significant reduction as far as mean % of correctly perceived words is concerned.



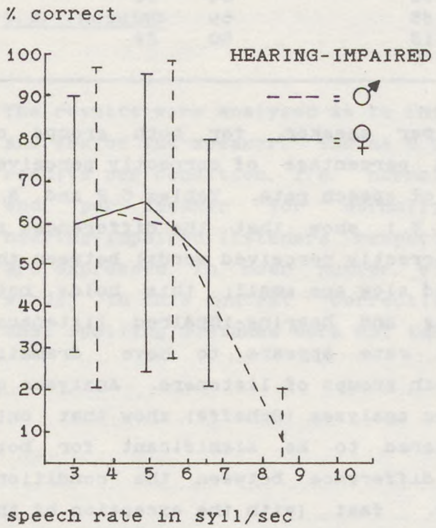


Figure 5.1: Mean percentage of correctly perceived words as a function of speech rate, per speaker, for normally hearing and hearing-impaired listeners

5.4. Discussion

Whereas the differences in test results for the two listener groups - as far as the conditions normal and slow are concerned - are almost negligible, the differences in standard deviations (see tables 5.2, 5.3 and figure 5.1) are remarkable. As an explanation for the high standard deviations in the case of the hearing-impaired listeners the following two reasons can be given:

1) Since the only prerequisite for participation in our test was that listeners should suffer from a congenital hearing loss of maximally 60 dB for the better ear, the results have been influenced by individual differences in hearing acuity among our listeners resulting in a large variability of the scores obtained.
2) The semantic complexity of the test material itself especially in connection with the age of our listeners (10-17 years). A further analysis concerning the level of complexity of the test material used in this experiment is reported on in chapter VI, section 6.5.

The fact that the difference in mean scores between the conditions normal and slow is very small seems to indicate that slowing down the rate of speech does not necessarily increase intelligibility. However, it should be noted that the results of the experiment reported on here were obtained with a population consisting of children who all belonged to the same age-group, viz. between 10 and 17. As regards possible implications of these results for the aged - whether they be suffering from a hearing impairment or not - further investigation is needed.
As to the speech rates as given in table 5.1 it is worth noting that compared to Van Balen (1980), who considered fragments with an average speech rate of 7.6 syllables per second to be fast, normal if between 7.6 and 5.6 and

slow from 5.6 downwards, our speech rates appear to be on the slow side (with the exception of the male speaker, fast condition).

With regard to the differences in speech rate between our two speakers we should like to mention that there are various ways in which a speaker may alter his/her rate, e.g. by changing the number of pauses, the rate of articulation or the duration of pauses (cf. Grosjean and Lane, 1974). The sentences used in this experiment were generally about 2 seconds and there were no pauses. The difference in the fast rate may be due to the fact that the female speaker continues to articulate in a very clear way whereas the male speaker's preciseness of articulation deteriorates with increasing speech rate.

5.5. Conclusion

As stated in the introduction, the aim of the experiments reported on here was to gain more insight into the influence of speech rate on the perception of speech by normally hearing and hearing-impaired listeners. Our conclusion is twofold.

Firstly, we failed to find a difference between normally hearing and hearing-impaired listeners as regards the relation between test results and speech rate. For both groups of listeners the point at which intelligibility begins to decline to a dramatically low level lies at about 6.5 syllables per second. This implies there is no indication that hearing-impaired listeners experience an extra handicap when confronted with speech spoken at a naturally fast rate, which appears to correspond well with the results of the investigations mentioned in section 5.1. However, as has already been stated in section 5.1. as well, the age of the listeners involved appears to be of significant influence on the discrimination scores for time-compressed speech. This means that performing our experiments with elderly subjects may yield completely different results. In this context we should like to mention Newman and Spitzer (1983), who measured the rate of processing pure-tone stimuli in elderly and young (normally hearing) subjects. They suggest an "age-associated slowing in auditory processing" which may account for the difference in performance between elderly and young subjects when confronted with time-compressed speech. Secondly, as far as the speech rates used in our experiment are concerned, the results do not provide support for the general assumption that slowing down the rate of speech results in improved intelligibility. This goes both for normally hearing and hearing-impaired listeners. As regards normally hearing listeners this is in accordance with the results of previous investigations of the intelligibility of rate-altered speech reported by Riensche et al. (1979). In the case of the hearing-impaired listeners, further investigation is needed before conclusions may be drawn concerning the influence of slowing down or speeding up speech rate on intelligibility.

[illegible]

investigations of the intelligibility of rate-altered speech reported by Picheny et al. (1979). In the case of the hearing-impaired listeners, further investigation is needed before conclusions may be drawn concerning the influence of slowing down or speeding up speech rate on intelligibility.

As stated in the introduction, the experiments reported on here aimed to gain more insight into the influence of speech rate on the perception of speech by normally hearing and hearing-impaired listeners. Our conclusion is twofold.

Firstly, we failed to find a difference between normally hearing and hearing-impaired listeners as regards the relation between test results and speech rate. For both groups of listeners the point at which intelligibility begins to decline to a dramatically low level lies at about 8.5 syllables per second. This implies there is no indication that hearing-impaired listeners experience an extra handicap when confronted with speech spoken at a naturally fast rate, which appears to correspond well with the results of the investigations mentioned in section 5.1. However, as has already been stated in section 6.1 as well, the age of the listeners involved appears to be of significant influence on the discrimination scores for time-compressed speech. This means that performing our experiments with elderly subjects may yield completely different results. In

Chapter VI

Conclusion

6.1. Introduction

In this final chapter we will evaluate in what way the conclusions obtained from our experimental work can be related to the aims of our study as stated in chapter I. Our study can be divided into two parts: an analysis of a much used set of Dutch PB word lists, the Utrecht lists, and the experimental work consisting of three experiments, each investigating a different prosodic cue, viz. accent, pitch contour and speech rate. In our summary of the conclusions drawn on the basis of the results of the above, we will keep to this order. Apart from summarizing our conclusions, some crucial matters already touched upon in the discussion of the results will be dealt with in greater detail. Finally, we will give some suggestions for possible further investigation.

6.2. Analysis of the Utrecht lists

As part of an endeavour to gain insight into the current status of speech audiometry tests in the Netherlands, the Utrecht lists - considered to constitute a representative sample of Dutch test material - were analyzed as to two claims generally made with respect to these lists, viz. equivalence as regards the distribution of words with a certain number of phonemes, and phonetic balance. In addition we dealt with the question whether the words occurring in the Utrecht-lists can be regarded as being representative of normal language use. The following conclusions were drawn:

- the claim of an equal distribution of words per word length in phonemes is justified. However, it should be noted that this goes for words consisting 2, 3 or 4 phonemes only, i.e. our conclusion does not include the (few) words with 5 or 6 phonemes.
- the frequency of occurrence of phonemes in the Utrecht lists appeared to differ considerably from the phoneme distribution in normal language use.
- with regard to the question whether the words occurring in the Utrecht lists can be considered representative of normal language use, the results of our analysis give us the impression that the words were selected on the basis of their frequency of occurrence in the Dutch language, i.e. few highly infrequent words.

Trying to relate the above conclusions to what we hoped to achieve by carrying out this investigation, viz. to contribute to the (eventual) construction of test material that provides a realistic estimate of a hearing-impaired person's ability to understand speech in everyday communication, we cannot refrain from concluding that the compilation of a new, more standardized, Dutch speech audiometry test certainly deserves attention. However, although the results of our analysis seem to indicate that the material used in the Utrecht lists differs from normal language use as regards distribution of phonemes and frequency of occurrence of the words used, these results should be viewed with reservation for the following reasons. Firstly, because of the absence of a representative phoneme frequency count for Dutch and secondly as the large number of highly infrequent words occurring in the Uit den Boogaart (1975) word frequency count leads us to doubt its representativeness for the Dutch language.

6.3. Accent

The first of our series of three experiments was concerned with the question whether - on the sentence level - accent influences the speech decoding process of normally hearing and hearing-impaired listeners in the same manner. The variables investigated were accented vs. unaccented words, position of sentence accent (i.e. accented word) and sex of the speaker.

It appeared that accented words were perceived better by both normally hearing and hearing-impaired listeners. This is not surprising in view of the fact that accented words are generally longer, louder and often contain a pitch movement, which should make them more intelligible. As to the position of the sentence accent, the results of our experiment induce us to think that - in this respect - there is a difference in listening strategy between normally hearing and hearing-impaired listeners. Whereas normally hearing listeners seemed to make use of the prosodic information provided by the preceding intonation contour and consequently scored higher on accented words in the middle accent position, hearing-impaired listeners appeared to follow a completely different strategy. They scored highest when the accent occurred in the beginning of the sentence, which seems to indicate that intensity - declining towards the end of the sentence - provides a stronger cue than prosodic information as provided by the intonation contour.

As for speaker variation the overall percentage of correct responses appeared to be highest in the case of the female speaker. However, generalizing this finding would not be justified because of:

1) the frequent use of the fall pattern (the least common Dutch pitch pattern, cf. Collier, 1972) by our male speaker.

2) the speech rate of our female speaker, which appeared to be slower than that of the male speaker.

3) the fact that only one male and one female speaker were used in our experiment.

Besides investigating the influence of sentence accent, we also tried to find out more about the validity of pure-tone testing as a means to estimate ability to understand everyday speech. For this purpose we compared the pure-tone audiograms of our hearing-impaired subjects with their test results. The results of this comparison did not enable us to find a clear relation between tone audiograms and test results. As regards the aims of our study, our results seem to indicate that as far as accent is concerned the listening strategy followed by hearing-impaired listeners differs from the one followed by normally hearing listeners. Whereas normally hearing listeners make use of prosodic information and linguistic expectations to understand speech under reduced redundancy conditions, intensity remains the most important cue for hearing-impaired listeners. On the whole these conclusions - though of a tentative nature - indicate that further investigation into this matter would certainly be warranted.

6.4. Pitch contour

Our second experiment dealt with the role of pitch contour in the perception of speech (i.e. sentences) by normally hearing and hearing-impaired listeners. By pitch contour is understood the overall pitch contour of sentences. The variables investigated were normally intonated vs. monotonized sentences and sex of the speaker. The results of this experiment indicate that the overall pitch contour of a sentence contributes to its intelligibility as normally intonated sentences were perceived better than monotonized sentences by both normally hearing and hearing-impaired listeners. This means that the role played by pitch contour in the perception of speech by normally hearing and hearing-impaired listeners seems to be of a similar nature. As for speaker variation the results of this experiment do not enable us to draw any conclusions with regard to the possible influence of this variable; the differences in mean scores were small.

Relating the above results to the starting-point of our investigation, the possible difference in listening strategy between normally hearing and hearing-impaired listeners, we have to admit that the fact that the overall pitch contour plays an important role in the perception of speech by the hearing-impaired is not very surprising in view of the successful use made of pitch information as an aid to lip-reading and in cochlear stimulation (for references see chapter IV, section 4.1 and below). However, this is not in accordance with our expectations based on the results of the first experiment, in which we did find a difference in listening strategy between normally hearing and hearing-impaired listeners as regards accent.

As to the subject of cochlear stimulation we should like to give a brief summary of the research carried out in this field. For a detailed review the reader is referred to Risberg (1982). Since the end of the 1960's investigations have been carried out at several laboratories concerning the direct stimulation of the auditory nerve by means of cochlear implants.

So far most researchers working on cochlear implants have assumed that the only way to obtain some ability to perceive speech in such systems is by following a multichannel approach, i.e. developing systems that copy the frequency-analyzing ability of the peripheral auditory system. Results obtained with multichannel systems are reported by e.g. the cochlear implant group in Australia (Tong, Clark, Dowell, Martin, Seligman and Patrick, 1981). A disadvantage of multichannel cochlear implants is the amount of electronic circuitry involved.

As regards single channel cochlear prostheses the following can be said. During the first twenty years of research in the field of cochlear implants it was generally believed that single channel systems could only transmit information about speech rhythm and some information about environmental sounds (Zwicker and Zollner, 1980). Single channel systems do not try to stimulate the frequency-analyzing ability of the peripheral auditory system but make use of the time

domain properties of the system (cf. Keidel, 1980). In a fairly recent study performed by the Vienna group working on cochlear implants some extremely good results obtained with a single channel stimulator are reported (cf. Hochmair-Desoyer, Hochmair, Burian and Fischer, 1981).
Apart from stimulation inside the cochlea, extracochlear stimulation, which is attractive as it requires no irreversible operation, is also studied in several laboratories - among others - by Fourcin and his associates in London (cf. e.g. Fourcin, 1983). The good results obtained with cochlear implants will undoubtedly cause a further increase in experiments in this area. However, as long as the problem as to what the electronic circuit should do has not been adequately solved yet, it is obvious that more research especially as regards speech processing and the importance of different speech elements for the perception of speech (both with and without the support of lip-reading) should be given priority.

6.5. Speech rate

Our third experiment was concerned with speech rate. This experiment was carried out in an attempt to find an answer to the question whether speech rate - being an important prosodic cue - is of comparable influence on the speech decoding process of normally hearing and hearing-impaired listeners. To this end the intelligibility of sentences spoken at three different speech rates (viz. normal, slow and fast) by a male and a female speaker was investigated.
As regards the influence of speech rate, we did not find a difference between normally hearing and hearing-impaired listeners. For both groups the point at which intelligibility begins to decline dramatically appeared to lie at about 6.5 syllables per second. As for our two speakers, there appeared to be a difference

in average speech rate, i.e. in all three conditions (normal, slow and fast) the speech rate of our female speaker was slower than that of the male speaker. Returning to the aims of our investigation this result may tempt us to conclude that hearing-impaired listeners do not experience an extra handicap when confronted with speech spoken at a (naturally) fast rate. However, as far as possible incorporation in speech audiometry tests is concerned, we should bear in mind that our results were obtained with children all belonging to the same age-group, viz. 10-17 years. There is evidence from various studies (for references see chapter V, sections 5.1 and 5.5) that the age of the listener involved is of significant influence on the discrimination scores for time-compressed speech. Consequently, performing the same experiments with e.g. elderly subjects may yield completely different results. Besides, in view of the variability of the test scores obtained we are not able to draw any firm conclusions with regard to the influence of speech rate.

6.6. Problems involved in speech intelligibility testing: our own experiences

6.6.1. Introduction

Reading the summary of our experimental work and the conclusions drawn on the basis of its results, one may be inclined to conclude that apart from accentuation, no differences in the role of prosody could be established between normally hearing and hearing-impaired listeners. Nevertheless, we should like to emphasize the exploratory character of this investigation, and our feeling that - in this respect - we did manage to achieve one of our aims, viz. to find out more about the possible differences in listening strategy between normally hearing and hearing-impaired listeners as regards the influence of prosody. One clear conclusion that can be drawn is that there is an obvious need for further investigation into this matter. As far as the compilation of a new Dutch speech audiometry test is concerned we have already referred to a project started at the Department of Audiology, University Hospital, Utrecht. Before coming up with suggestions for further investigation, we should like to deal with some of the main problems encountered in carrying out this study.

6.6.2. Variability of scores in the listening tests

We chose to discuss the above problem first as we realize it to be one of the problematic aspects of this study. Is it justified to draw conclusions when the test scores appear to vary so much as shown by the extremely high standard deviations? Of course, this question occurred to us more than once. However, the aim of our investigation was to gain insight into the influence of prosodic factors on the perception of speech by "the hearing-impaired". By "the hearing-impaired" is meant hearing-impaired persons in general. Consequently, our experiments were intended to provide an intelligibility measure of a general "broad" nature instead of providing a measure of a hearing-impaired individual's ability to perceive speech.
Retrospectively, we are inclined to say that we set ourselves an impossible task as "the hearing-impaired" do not exist. Individual differences in hearing acuity depending on its clinical cause, vocabulary size, experience in test taking etc. make it impossible to find a homogeneous population. The fact that as far as the latter two experiments (pitch contour and speech rate) are concerned our hearing-impaired subjects all suffered from a congenital hearing loss of maximally 60 dB for the better ear, all belonged to the same age-group (10 to 17 years) and were comparable as

regards level of education does not mean that they are representative of "the hearing-impaired" in general.

6.6.3. Subjects

As mentioned above, individual differences between subjects may result in a large variability of test scores. However, our main reason to opt for children suffering from a congenital hearing loss was the hope of excluding differences in vocabulary size due to the onset of the handicap. We are well aware that due to this choice the results obtained only apply to hearing-impaired listeners belonging to this particular group. This is especially clear in the case of the speech rate experiment, the results of which do not appear to correspond with evidence from studies concerned with elderly hearing-impaired subjects.

6.6.4. Noise

In all three experiments the sentences were masked with noise. We decided to do so for two reasons:

1) because we are interested in the difficulties experienced by hearing-impaired listeners in understanding speech in an everyday communication situation, in which noise coming from various sources is usually present.
2) in order to prevent ceiling effects in the case of normally hearing listeners.

Although in both cases (normally hearing and hearing-impaired listeners) we tried to find an S/N ratio that would yield approximately 50% correct responses, we did not always succeed in spite of extensive pilot work. The difficulties we encountered in determining the proper S/N ratio seem to indicate that the masking effect of noise is hard to predict. As far as this investigation is concerned the combination of speech noise (i.e. noise with the long term average spectrum of speech) and LPC speech (i.e. speech generated by means of LPC analysis) appeared to have an unexpectedly negative effect on intelligibility (cf. chapter IV, section 4.4).

6.6.5. Test material

As we are interested in the difficulties experienced by the hearing-impaired in perceiving everyday - and consequently - connected speech and the possible influence of prosodic factors, it is obvious that our test material should consist of sentences. The fact that we thought it important to use natural speech in order to approach day-to-day conversation as closely as possible implies that although our test sentences (which do not form a coherent whole but stand on their own) had been developed to satisfy a number of criteria (cf. chapter III, section 3.2.1.1 and chapter IV, section 4.2.1), there may be other factors, which, in spite of their influence on the intelligibility of the speech stimuli, have not been controlled. We should like to deal with one of these factors in somewhat greater detail, viz. test difficulty.
A close analysis of the results of our second experiment (pitch contour) showed that some sentences, although presented under identical conditions, were considerably less intelligible than others. We therefore decided to offer our test material to a group of speech therapists and teachers of schools for hearing-impaired children with the request to judge our material with regard to its being "far from" vs. "close to" the world experienced by a hearing-impaired child aged between 10 and 17. Their judgements appeared to correspond with our test results, i.e. sentences that were judged to be "far from" the world experienced by hearing-impaired children belonging to the age-group at issue appeared to

be least intelligible (cf. e.g. Appendix C: sentences 4 and 5, monotonized, and sentence 1, intonated). Although the results of our enquiry provide an interesting starting-point for further - close - analysis of our test material as regards level of difficulty, lack of time prevented us from making such an analysis.

6.6.6. Suggestions for further investigation

6.6.6.1. Introduction

In view of its exploratory character, our study should not be considered as a finished piece of work but as a beginning. Consequently, the suggestions for further investigation to be given in this section are all - more or less - based on difficulties experienced in the process of carrying out this investigation. The suggestions will be given in order of occurrence, i.e. per chapter.

6.6.6.2. Chapter II

With a view to being able to investigate the degree of phonetic balance of speech audiometry tests, there is a definite need for a representative phoneme frequency count for Dutch. However, from a phonetic point of view it seems even more interesting to investigate the transitional probabilities of phonemes as the intelligibility of phonemes is believed to be affected by the context in which they occur. This means that the perception of a given phoneme may be influenced by the coarticulation effects of its neighbours. Apart from investigating the distribution of phonemes, we should also like to mention the need for further investigation as regards word frequency. The high number of extremely infrequent words occurring in the Uit den Boogaart corpus, give us the impression that this Dutch word frequency count should be improved upon.

6.6.6.3. Chapter III

On the basis of the results of this experiment, the conclusion was drawn that in the case of hearing-impaired listeners the strongest cue for intelligibility is provided by intensity. However, as far as the intelligibility of accented words is concerned it would also be interesting to investigate the influence of duration. Besides, further investigation into the influence of prosodic knowledge and linguistic expectations on the perception of speech by the hearing-impaired also deserves attention.

6.6.6.4. Chapter IV

We have already referred to the unpredictable character of the masking effects of (speech) noise but the results of our study aroused our special interest in the combination of speech noise and LPC speech, which - as far as this study is concerned - appeared to have a dramatic effect on intelligibility. Apart from the results as presented by Van Loon (1984), who found that the masking effect of speech noise differs depending on whether it is used to mask natural speech or speech generated by means of LPC analysis, we did not manage to find other examples of investigations into this matter.

6.6.6.5. Chapter V

As has already been stated, our results in this chapter are not in accordance with evidence obtained from studies involving elderly hearing-impaired subjects. The influence of speech rate on the perception of speech by hearing-impaired listeners belonging to different age-groups seems to be an interesting subject for further investigation.
As to the point at which intelligibility begins to decline substantially (viz. 6.5 syllables per second), further investigation should measure intelligibility at various points along the intelligibility curve in order to find out what happens between 6.5 and 8.5 syllables per second (cf. chapter V, section 5.3). Besides, the fact that we failed to find evidence for the general assumption that slowing down the rate of speech results in improved intelligibility also requires further investigation, especially with regard to hearing-impaired listeners.

6.7. Some concluding observations

In this final section we should like to come back to the three different ways of approaching the hearing problem mentioned in our introductory chapter, viz. from a traditional, an ecological and a phonetic point of view. Summarizing, we believe that as regards trying to provide a realistic estimate of a hearing-impaired individual's ability to perceive everyday speech, each of these three approaches has certain merits.
With regard to the traditional approach we should like to quote Catlin (1984), who states that "speech tests are generally used as supportive information when predicting pure-tone thresholds, rather than as indicators of speech under 'everyday conditions' " (p. 249). This implies that speech tests do have validity

as far as the measurement of hearing ability is concerned but should not be expected to provide an estimate of a hearing-impaired patient's performance in everyday communication. The fact that speech tests do not appear to give an indication of the difficulties a hearing-impaired person experiences in day-to-day conversation can be explained in various ways.

A possible reason may be that the strive for ease of administration, universality of application and standardization has compromised the value of speech tests. In this context it is worth noting that pure-tone tests as good examples of tests that are universally applicable and extremely well standardized have always been very popular. Returning to the controversy whether or not the assessment of hearing by means of pure-tone audiometry is valid for estimating degree of hearing handicap for speech (cf. also chapter I, section 1.4.1) we should like to state the following. In our opinion pure-tone audiometry is a valid way of testing hearing ability but should only be used to predict everyday hearing performance in combination with evidence obtained from speech tests. Both pure-tone and speech tests should form part of an extensive test battery designed to provide a more realistic estimate of a patient's hearing performance in everyday situations.

As regards speech tests we cannot refrain from saying that whereas speech tests that conform closely to the demands made by standardization appear to be unrelated to everyday hearing experience those tests that are designed to approach day-to-day conversation as closely as possible often provide such variable results that no firm conclusions can be drawn from them.

As for ecological approaches to hearing we agree with Noble (1983) in the sense that in order to gain more insight into the problems experienced by the hearing-impaired in everyday communication, we should make use of their own obvious expertise by means of e.g. self-report. Self-report questionnaires may provide valuable, additional information when trying to predict a patient's hearing performance in everyday life.

As regards our own phonetic approach to the hearing problem it has already been stated that our main interest lies in the process of communication and consequently in factors that may influence this process. As studies concerning the role of prosodic factors in the perception of speech by the normally hearing have proved their importance, we wanted to find out whether these factors could be shown to play a comparable role in the perception of speech by the hearing-impaired. Although - apart from accent - we did not manage to establish any clear differences in listening strategy between normally hearing and hearing-impaired listeners, the results of this pilot study certainly justify further investigation into this matter. We think that results of research concerning the listening strategy of the hearing-impaired should certainly be taken into account when constructing a test battery that does provide a reliable estimate of a patient's everyday hearing performance.

Finally, we should like to emphasize that when discussing the hearing problem we should always bear in mind from what point of view the problem is approached. This means that we are aware that in clinical settings (speech) audiometry tests should primarily provide an efficient, valid diagnosis. Nevertheless, we think that the tests currently used for the purpose of speech audiometry could be improved by adding test material in which findings obtained from both self-report and phonetic research are incorporated.

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on everyday hearing performance. Tests which are designed to approach day-to-day conversation as closely as possible often provide such variable results that no firm conclusions can be drawn from them.

As for "ecological approaches" to hearing we agree with Noble (1983) in the sense that in order to gain more insight into the problems experienced by the hearing-impaired in everyday communication, we should make use of their own obvious expertise by means of e.g. self-report. Self-report questionnaires may provide valuable, additional information when trying to predict a patient's hearing performance in everyday life.

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Appendix A

Utrecht lists

4 broek	2 oog	4 stoel	3 drie	4 hand
3 baal	4 land	3 mak	3 rat	4 blik
3 dauw	3 voor	3 zien	3 zaad	3 roer
3 zijn	4 gids	3 doos	4 licht	3 zaak
4 borg	2 en	2 nu	4 drom	4 drek
3 zak	3 haan	3 maag	4 hoest	2 dij
3 mes	3 diep	3 dus	3 weg	4 worm
4 lans	3 duf	3 vuil	3 vlo	4 dans
3 doop	3 rijm	3 peen	3 pen	2 ze
3 vijg	4 proef	3 vet	3 bas	2 mee

3 duf	4 zink	3 loop	3 muur	3 maar
4 stoom	2 ja	3 haar	4 lint	3 koor
4 mand	4 gans	4 wind	3 kaak	3 jan
3 zon	3 niet	3 zang	3 room	4 bril
3 weer	3 vos	3 eend	3 nar	3 beek
3 ding	2 lei	3 dit	4 fles	4 spijl
2 een	4 voort	3 mijn	4 wand	3 nog
3 vaal	3 hen	2 te	3 dood	2 ge
3 lief	3 hoed	4 tros	5 gunst	4 zelf
3 duim	3 nuf	3 ven	3 dop	3 lap

4 troep	3 maal	3 daar	3 ruim	3 raam
3 maan	3 zet	3 jas	4 zwaan	3 kees
3 wil	3 moor	4 dweil	3 doek	3 ham
3 door	3 tien	3 bier	3 gat	4 woord
3 gang	4 kans	4 vlek	3 hoor	4 jacht
2 zij	3 hout	4 dank	4 gist	4 gips
3 dek	4 dons	2 oud	4 berg	3 wijn
3 nis	3 ruit	4 kust	3 fier	4 berk
4 mus	3 gek	3 bon	3 nek	3 duur
3 biet	3 las	4 stuk	3 lat	3 laf

4 pink	3 wat	3 poes	3 gauw	3 boer
4 graan	4 moord	3 hooi	3 man	4 gras
2 eer	3 haat	4 kruis	4 jicht	2 ma
3 rood	3 been	3 het	2 er	2 is
3 dak	3 min	2 nee	3 dier	3 doof
4 wicht	3 zien	4 wacht	3 veel	3 ziek
4 dorp	3 neer	3 gil	4 heks	3 toon
3 net	3 dol	3 dijk	3 zuur	3 veen
3 buur	4 heft	3 rot	3 naad	4 lens
4 tand	3 rein	3 lach	3 ton	3 gom

Appendix B

—— early accent

==== middle accent

~~~~ late accent

1. Zijn jullie daar nog nooit samen geweest?

   (Haven't you ever been there together before?)

2. Wil jij morgen weer hier blijven slapen?

   (Would you like to spend the night here again tomorrow?)

3. Hebben jullie die vraag goed beantwoord?

   (Have you answered that question correctly?)

4. Heeft het hier deze week veel geregend?

   (Did it rain a lot here this week?)

5. Hoeveel flessen melk drink jij per week?

   (How many bottles of milk do you drink a week?)

6. Ging haar man om drie uur naar de buurvrouw?

   (Did her husband go to the neighbour at three o'clock?)

7. Heb jij vandaag bij moeder gegeten?

   (Did you have dinner at mother's today?)

8. Zijn jullie samen naar die kerk geweest?

   (Have you been to that church together?)
~~~~

9. Waren er twee koeien in dit weiland?

(Were there two cows in this meadow?)

10. Heeft hij jouw auto vandaag gewassen?

(Did he wash your car today?)

11. Vinden jullie brood met kaas niet lekker?

(Don't you like cheese sandwiches?)

12. Zijn zij toen samen naar de stad geweest?

(Did they go to town together at that time?)

13. Heeft hij meer bonen gegeten dan ik?

(Has he eaten more beans than I?)

14. Zijn er in dit dorp veel huizen gebouwd?

(Have a lot of houses been built in this village?)

15. Heb jij gisteren een uur gewandeld?

(Did you take an hour's walk yesterday?)

Appendix C

Intonation experiment

Monotonized sentences:	speaker:
1. De spoortrein was al gauw kapot (The train broke down quite soon)	female
2. De jongen werd stevig aangepakt (The boy was treated forcefully)	male
3. De kachel is nog steeds niet aan (The heater is not on yet)	female
4. Het loket bleef lang gesloten (The till remained closed for a long time)	male
5. Spoedig kwam er een einde aan (Soon it came to an end)	female

Intonated sentences:	
1. Zijn manier van werken ligt mij niet (His way of working does not suit me)	female
2. De aardappels liggen in de schuur (The potatoes are in the shed)	male
3. De tuinman heeft het gras gemaaid (The gardener has mown the grass)	female
4. Zijn gezicht heeft een rode kleur (His face has a red colour)	male
5. De bel van de voordeur is kapot (The front door bell is out of order)	female

Speech rate experiment

1. De nieuwe fiets is gestolen
   (The new bike has been stolen)

2. Het slot van de voordeur is kapot
   (The front door lock is out of order)

3. Er werd een diepe kuil gegraven
   (A deep hole was being dug)

4. Van de viool is een snaar kapot
   (The violin has a broken string)

5. Zijn fantasie kent geen grenzen
   (There is no limit to his fantasy)

6. Voor het eerst was er nieuwe haring
   (For the first time there was fresh herring)

7. Ieder half uur komt hier een bus langs
   (A bus passes here every half hour)

8. De wind waait vandaag uit het westen
   (The wind is blowing from the west today)

9. Het begon vroeg donker te worden
   (It began to get dark early)

10. Deze kerk moet gesloopt worden
    (This church has to be demolished)

11. Het gras was helemaal verdroogd
    (The grass was all dried up)

12. Zijn leeftijd ligt boven de dertig
    (His age is over thirty)

13. Dat hotel heeft een slechte naam
    (That hotel has a bad name)

14. Het dak moet nodig hersteld worden
(The roof needs repair urgently)

15. De appels aan de boom zijn rijp
(The apples on the tree are ripe)

<u>Speech rate experiment</u>

1. De nieuwe fiets is gestolen
   (The new bike has been stolen)

2. Het slot van de voordeur is kapot
   (The front door lock is out of order)

3. Er werd een diepe kuil gegraven
   (A deep hole was being dug)

4. Van de viool is een snaar kapot
   (The violin has a broken string)

5. Zijn fantasie kent geen grenzen
   (There is no limit to his fantasy)

6. Voor het eerst was er nieuwe haring
   (For the first time there was fresh herring)

7. Ieder half uur komt hier een bus langs
   (A bus passes here every half hour)

8. De wind waait vandaag uit het oosten
   (The wind is blowing from the east today)

9. Het begon vroeg donker te worden
   (It began to get dark early)

10. Deze kerk moet gesloopt worden
    (This church has to be demolished)

11. Het gras was helemaal verdroogd
    (The grass was all dried up)

12. Zijn leeftijd ligt boven de dertig
    (His age is over thirty)

13. Dat hotel heeft een slechte naam
    (That hotel has a bad name)

Appendix D (hearing-impaired subjects)

Practice items:

1. De bal vloog over de schutting (slow rate, male speaker)
(The ball flew across the fence)

2. Morgen wil ik maar een liter melk (monotonized, male speaker)
(Tomorrow I want only one litre of milk)

3. Het natte hout sist in het vuur (intonated, female speaker)
(The wet wood is hissing in the fire)

4. Alle prijzen waren verhoogd (fast rate, female speaker)
(All prices had been raised)

Test sentences:

5. Deze kerk moet gesloopt worden (normal rate, female speaker)
(This church has to be demolished)

6. De spoortrein was al gauw kapot (monotonized, female speaker)
(The train broke down quite soon)

7. De nieuwe fiets is gestolen (slow rate, female speaker)
(The new bike has been stolen)

8. Zijn manier van werken ligt mij niet (intonated, female speaker)
(His way of working does not suit me)

9. Het slot van de voordeur is kapot (fast rate, female speaker)
(The front door lock is out of order)

10. Dat hotel heeft een slechte naam (normal rate, male speaker)
(That hotel has a bad name)

11. De jongen werd stevig aangepakt (monotonized, male speaker)
(The boy was treated forcefully)

12. Zijn fantasie kent geen grenzen (slow rate, male speaker)
(There is no limit to his fantasy)

13. De aardappels liggen in de schuur (intonated, male speaker)
(The potatoes are in the shed)

14. Zijn leeftijd ligt boven de dertig (fast rate, male speaker)
(His age is over thirty)

15. Het dak moet nodig hersteld worden (normal rate, female speaker)
(The roof needs repair urgently)

16. De kachel is nog steeds niet aan (monotonized, female speaker)
(The heater is not on yet)

17. Van de viool is een snaar kapot (slow rate, female speaker)
(The violin has a broken string)

18. De tuinman heeft het gras gemaaid (intonated, female speaker)
(The gardener has mown the grass)

19. De appels aan de boom zijn rijp (fast rate, female speaker)
(The apples on the tree are ripe)

20. Voor het eerst was er nieuwe haring (normal rate, male speaker)
(For the first time there was fresh herring)

21. Het loket bleef lang gesloten (monotonized, male speaker)
(The till remained closed for a long time)

22. Er werd een diepe kuil gegraven (slow rate, male speaker)
(A deep hole was being dug)

23. Zijn gezicht heeft een rode kleur (intonated, male speaker)
(His face has a red colour)

24. Het begon vroeg donker te worden (fast rate, male speaker)
(It began to get dark early)

25. Het gras was helemaal verdroogd (normal rate, female speaker)
(The grass was all dried up)

26. Spoedig kwam er een einde aan (monotonized, female speaker)
(Soon it came to an end)

27. Ieder half uur komt hier een bus langs (slow rate, female speaker)
(A bus passes here every half hour)

28. De bel van de voordeur is kapot (intonated, female speaker)
(The front door bell is out of order)

29. De wind waait vandaag uit het westen (fast rate, female speaker)
(The wind is blowing from the west today)

13. [illegible]
(The potatoes are in the shed)

14. Zijn l[illegible]
(His age is over thirty)

15. [illegible]
(The roof needs repair [illegible])

16. De kachel is nog steeds niet aan (monotonised, female speaker)
(The heater is not on yet)

17. Van de viool is een snaar kapot (slow rate, female speaker)
(The violin has a broken string)

18. De tuinman heeft het gras gemaaid (intonated, female speaker)
(The gardener has mown the grass)

19. De appels aan de boom zijn rijp (fast rate, female speaker)
(The apples on the tree are ripe)

20. Voor het eerst was er nieuwe haring (normal rate, male speaker)
(For the first time there was fresh herring)

21. Het loket bleef lang gesloten (monotonised, male speaker)
(The till remained closed for a long time)

22. Er werd een diepe kuil gegraven (slow rate, male speaker)
(A deep hole was being dug)

23. Zijn gezicht kreeg een rode kleur (intonated, male speaker)
(His face has a red colour)

24. Het begon vroeg donker te worden (fast rate, male speaker)
(It began to get dark early)

25. Het gras was helemaal verdroogd (normal rate, female speaker)
(The grass was all dried up)

26. Spoedig kwam er een einde aan (monotonised, female speaker)
(Soon it came to an end)

Appendix E (normally hearing subjects, test 1):

Practice items:

1. De trein kwam met een schok tot stilstand (normal rate, female speaker)
(The train stopped with a jerk)

2. De bal vloog over de schutting (slow rate, male speaker)
(The ball flew across the fence)

3. Morgen wil ik maar een liter melk (monotonized, male speaker)
(Tomorrow I want only one litre of milk)

4. Het natte hout sist in het vuur (intonated, female speaker)
(The wet wood is hissing in the fire)

5. Alle prijzen waren verhoogd (fast rate, female speaker)
(All prices had been raised)

Test sentences:

6. De nieuwe fiets is gestolen (normal rate, female speaker)
(The new bike has been stolen)

7. De spoortrein was al gauw kapot (monotonized, female speaker)
(The train broke down quite soon)

8. Het begon vroeg donker te worden (slow rate, female speaker)
(It began to get dark early)

9. De kachel is nog steeds niet aan (intonated, female speaker)
(The heater is not on yet)

10. Van de viool is een snaar kapot (fast rate, female speaker)
(The violin has a broken string)

11. Deze kerk moet gesloopt worden (normal rate, male speaker)
(This church has to be demolished)

12. Spoedig kwam er een einde aan (monotonized, male speaker)
(Soon it came to an end)

13. Het dak moet nodig hersteld worden (slow rate, male speaker)
(The roof needs repair urgently)

14. De jongen werd stevig aangepakt (intonated, male speaker)
(The boy was treated forcefully)

15. Het gras was helemaal verdroogd (fast rate, male speaker)
(The grass was all dried up)

16. Het slot van de voordeur is kapot (normal rate, female speaker)
(The front door lock is out of order)

17. De tuinman heeft het gras gemaaid (monotonized, female speaker)
(The gardener has mown the grass)

18. De appels aan de boom zijn rijp (slow rate, female speaker)
(The apples on the tree are ripe)

19. De bel van de voordeur is kapot (intonated, female speaker)
(The front door bell is out of order)

20. De wind waait vandaag uit het westen (fast rate, female speaker)
(The wind is blowing from the west today)

21. Dat hotel heeft een slechte naam (normal rate, male speaker)
(That hotel has a bad name)

22. Het loket bleef lang gesloten (monotonized, male speaker)
(The till remained closed for a long time)

23. Voor het eerst was er nieuwe haring (slow rate, male speaker)
(For the first time there was fresh herring)

24. Zijn manier van werken ligt mij niet (intonated, male speaker)
(His way of working does not suit me)

25. Zijn fantasie kent geen grenzen (fast rate, male speaker)
(There is no limit to his fantasy)

26. Er werd een diepe kuil gegraven (normal rate, female speaker)
(A deep hole was being dug)

27. De aardappels liggen in de schuur (monotonized, female speaker)
(The potatoes are in the shed)

28. Zijn leeftijd ligt boven de dertig (slow rate, female speaker)
(His age is over thirty)

29. Zijn gezicht heeft een rode kleur (intonated, female speaker)
(His face has a red colour)

30. Ieder half uur komt hier een bus langs (fast rate, female speaker)
(A bus passes here every half hour)

12. Spoedig [illegible]
(Soon it came to an end)

13. Het [illegible]
(The roof needs repair urgently)

14. De [illegible]
(The boy was treated correctly)

15. Het [illegible]
(The grass was all dried up)

16. [illegible]
(The front door lock is out of order)

17. De tuinman heeft het gras gemaaid (emotionless, female speaker)
(The gardener has mown the grass)

18. De appels aan de boom zijn rijp (slow rate, female speaker)
(The apples on the tree are ripe)

19. De bel van de voordeur is kapot (disinterested, female speaker)
(The front door bell is out of order)

20. De wind waait vandaag uit het westen (fast rate, female speaker)
(The wind is blowing from the west today)

21. Dat hotel heeft een slechte naam (normal rate, male speaker)
(That hotel has a bad name)

22. Het loket bleef lang gesloten (unemotional, male speaker)
(The till remained closed for a long time)

23. Voor het eerst was er nieuwe haring (slow rate, male speaker)
(For the first time there was fresh herring)

24. Zijn manier van werken bevalt mij niet (interested, male speaker)
(His way of working does not suit me)

25. Zijn fantasie kent geen grenzen (fast rate, male speaker)
(There is no limit to his fantasy)

Summary

Prosody has been firmly integrated into phonetic research. As regards normally hearing listeners, it is evident that prosodic factors play an important role in speech perception. The present study focuses on the question whether prosody can be shown to play a comparable part in the perception of speech by the hearing-impaired. By trying to find an answer to this question we hoped to be able to contribute to the improvement and/or development of test material used for the purpose of speech audiometry, i.e. the assessment of hearing by means of speech tests. Generally, speech audiometry is used following pure-tone audiometry as a means of assessing social handicap as well as the benefit of a particular hearing aid.

Within the context of this investigation we are especially interested in the social aspect of hearing impairment, i.e. the ability of a hearing-impaired individual to perceive speech in an everyday communication situation. We therefore decided to investigate the influence of three prosodic cues, viz. accent, pitch contours and speech rate, on the perception of sentences spoken by a male and a female speaker. For this purpose we performed three separate experiments each investigating a different prosodic cue and involving both normally hearing and hearing-impaired listeners.

Chapter I provides an introduction to the various angles from which the hearing problem can be approached. Apart from our own phonetic approach, two other possible ways of approaching the issue of hearing are mentioned. Besides, this chapter contains a survey of the development of both pure-tone and speech audiometry. Furthermore, some of the factors that are generally considered to be of importance in speech intelligibility testing are dealt with. Finally, the aims of the study are explained and an outline of the following chapters is given.

Chapter II briefly reviews the development of speech audiometry in the Netherlands especially with regard to the so-called PB (= Phonetically Balanced) word lists. In addition, an analysis of one of the most frequently used Dutch sets of PB word lists is reported on.

In chapter III the results of the first in our series of three experiments are presented. The experiment described concerns the influence of accent on the perception of speech by normally hearing and hearing-impaired listeners. By accent is understood sentence accent, which means that - for each sentence - our speakers had been instructed to make one pitch accent on the word underlined. The words to be accented could occur in three different positions in the sentence, viz. early, middle or late. Apart from an analysis of the results, a comparison of pure tone audiograms with test results is reported.

Chapter IV describes our second experiment dealing with the role of pitch contours in the perception of speech by normally hearing and hearing-impaired listeners. By pitch contours we understand the overall pitch contours constituting the intonation of sentences. The variables investigated are normally intonated vs. monotonized sentences and sex of the speaker.

Chapter V is concerned with our third and last experiment in which the influence of speech rate on the intelligibility of sentences spoken by a male and female speaker is investigated for normally hearing and hearing-impaired listeners.

In chapter VI the main conclusions drawn on the basis of the results of our experiments are summarized and related to the aims of our study. Moreover, some of the problems we experienced while carrying out this investigation are discussed in greater detail. The final two sections contain suggestions for further investigation as well as some concluding remarks concerning the three possible ways of approaching the hearing problem as stated in the first chapter.

Samenvatting

Sinds de vijftiger jaren zijn er in de audiometrie tests ontwikkeld die gebruik maken van spraakmateriaal. Deze tests, die meestal bestaan uit woordenlijsten, en waarvan er binnen het Nederlandse taalgebied een aantal voorkomen en worden toegepast, vormden een van de uitgangspunten van het hier beschreven onderzoek. Hoewel de verstaanbaarheid van losse woorden, al dan niet gebalanceerd, inzicht kan verschaffen in de specifieke aard van de gehoordeficiëntie, geeft niettemin de verstaanvaardigheid van de gehoorgestoorde luisteraar ten opzichte van hele zinnen een globaler inzicht in de mate van handicap zoals de luisteraar deze in dagelijkse situaties ervaart. Het testen met behulp van zinnen lijkt derhalve representatiever voor het vaststellen van de maatschappelijke gevolgen van de handicap.

Voordat we in staat zijn audiometrische tests te construeren die inzicht kunnen verschaffen in het functioneren van slechthorende luisteraars in dagelijkse communicatie is het van groot belang vast te stellen welke factoren hierbij van invloed zijn. Wat normaalhorende luisteraars betreft is het duidelijk dat prosodische factoren zoals b.v. intonatie, spreeksnelheid een grote rol spelen in de perceptie van lopende spraak (b.v. zinnen). De resultaten van fonetisch onderzoek aangaande de invloed van prosodie fungeerden eveneens als uitgangspunt voor ons onderzoek. Men kan zich immers afvragen in hoeverre prosodie ook van invloed is op de spraakperceptie bij slechthorenden. Bovendien, zou het aanbeveling verdienen eventuele resultaten van een onderzoek met een dergelijke vraag als uitgangspunt te verwerken in audiometrische tests die gebruik maken van lopende spraak.

Op grond van bovenstaande overwegingen hebben we besloten de invloed van drie prosodische factoren, n.l. klemtoon, intonatie en spreeksnelheid, op de verstaanbaarheid van zinnen te onderzoeken. Alle zinnen

werden door een mannelijke en een vrouwelijke spreker ingesproken. Elk van de drie factoren werd in een afzonderlijk experiment onderzocht waaraan zowel slechthorende als normaalhorende proefpersonen deelnamen.
Hoofdstuk I bevat een inleiding met betrekking tot de verschillende invalshoeken van waaruit men slechthorendheid kan benaderen. Naast de fonetische benadering waarvoor hier werd gekozen, worden ook twee andere benaderingswijzen besproken. Bovendien wordt er een overzicht gegeven van de ontwikkeling van toon- en spraakaudiometrie. Tenslotte, worden de doelstellingen van het onderzoek uiteengezet en wordt de inhoud van de volgende hoofdstukken kort samengevat.
Hoofdstuk II behandelt de ontwikkeling van spraakaudiometrie in Nederland in het bijzonder met betrekking tot de zg. PB (= fonetisch gebalanceerd) woordenlijsten. Een analyse van de Utrechtse lijsten, een van de meest gebruikte sets van PB lijsten, laat zien dat het samenstellen van nieuw meer gestandaardizeerd testmateriaal aanbeveling verdient.
In hoofdstuk III worden de resultaten van het eerste experiment, waarin klemtoon centraal stond, beschreven. De invloed van de plaats van de klemtoon in de zin (d.w.z. vroeg, midden of laat) blijkt te verschillen bij normaalhorende en slechthorende luisteraars. Verschil in sprekerstem lijkt niet van invloed te zijn. Een vergelijking van de toonaudiogrammen van de slechthorende proefpersonen met hun testresultaten laat geen duidelijk verband zien.
Hoofdstuk IV beschrijft het tweede experiment waarin de invloed van intonatie (monotoon vs. natuurlijk) werd onderzocht. Zowel bij normaalhorende als slechthorende luisteraars blijkt de aanwezigheid van toonhoogtebewegingen de verstaanbaarheid van zinnen positief te beinvloeden; dit geldt voor beide sprekers.
Hoofdstuk V behandelt de resultaten van het derde experiment, waarin de invloed van spreeksnelheid onderzocht werd. De resultaten van dit experiment laten zien dat wanneer het spreektempo een bepaalde grens

overschrijdt (d.w.z. hier 6.5 syllaben per seconde) de verstaanbaarheid voor beide populaties drastisch afneemt. Hoewel we op basis van deze resultaten geneigd zijn te veronderstellen dat slechthorenden geen extra handicap ondervinden wanneer ze geconfronteerd worden met een hoge spreeksnelheid, moet hierbij opgemerkt worden dat de slechthorende populatie bestond uit kinderen in de leeftijdsgroep van 10 tot 17 jaar. Hetzelfde experiment uitgevoerd met een oudere slechthorende populatie zou waarschijnlijk geheel andere resultaten opleveren.

In hoofdstuk VI worden de belangrijkste konklusies die op basis van de experimentele resultaten getrokken kunnen worden samengevat. Verder worden een aantal problemen waarmee we tijdens het uitvoeren van dit onderzoek te maken kregen nader uitgewerkt. Tenslotte worden er suggesties gedaan voor mogelijk verder onderzoek.

STELLINGEN

1. Communicatie beperkt zich niet tot interactie tussen mensen. Communicatie met een andere soort geeft - sommige mensen - aanzienlijk meer voldoening dan communicatie van mens tot mens.
(cf. W. Noble (1983) Audiology 22: 325-338)

2. Zowel het zoeken naar "het normale gehoor" als het zoeken naar "de" methode om de mate van auditieve handicap te kwantificeren kunnen vergeleken worden met het zoeken naar de Graal, d.w.z. beiden zullen voorlopig waarschijnlijk niet gevonden worden.
(cf. W.D. Ward (1983) Audiology 22: 313-324)

3. Het feit dat slechthorenden gewend zijn spraak in min of meer "aangetaste" vorm waar te nemen leidt tot een vertekend beeld bij de resultaten van perceptie experimenten waarin gebruik wordt gemaakt van een met opzet "aangetast" spraaksignaal.

4. Het gebruik van ruis als spraakmaskering bij luisterproeven leidt tot gefrustreerde onderzoekers.

5. De interne organisatie zou het visitekaartje van iedere HEAO (= Hoger Economisch en Administratief Onderwijs) behoren te zijn.

6. De toename van het aantal proefschriften dat het eindpunt vormt van een wetenschappelijke carrière is een betreurenswaardige ontwikkeling.

7. "Life starts at forty" voor Engelse leraren die op hun veertigste verjaardag uit het onderwijs stappen.

8. Tengevolge van een omissie in de Nederlandse taal zijn samenwonenden gedwongen hun leven lang elkaars "vrienden" te blijven.

9. Moderne literatuur : is er van die film al een boek gemaakt ?

10. Vrouwen-en-management beperkt zich tot cursussen.

11. De moderne HBO-student geeft de voorkeur aan gestencilde prefab kennis die slechts hoeft te worden opgeborgen.

Stellingen behorende bij het proefschrift "The influence of prosodic parameters on the perception of speech by normally hearing and hearing-impaired listeners: an exploratory study", M. Vingerling, Utrecht, 27 maart 1987.