Beyond lips: Components of speechreading skill

by

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Abstract

The purpose of the present thesis was threefold. First, to study perceptual and cognitive correlates to individual differences in speechreading performance. Second, to examine certain aspects of word-decoding/discrimination in the speechreading process. Third, to investigate whether hearing-impaired individuals compensate for their hearing loss by means of improved speechreading ability. The results demonstrate that individual differences on a set of perceptual and cognitive component processes were related to speechreading either directly or indirectly, and could also be classified as influencing speechreading generally or specifically. Based on this 2 by 2 taxonomy, it was thus possible to establish which kind of relationship and what kind of effect a certain cognitive component is responsible for in speechreading. The results also indicate that there are similarities between visual and auditory speech perception in the temporal order that words are recognized. A process model for speechreading was also developed and further test implications were delineated. The results do not indicate that hearing-impaired individuals compensate for their hearing loss by means of an improved speechreading ability, neither do they rely on a different set of cognitive components for successful speechreading.

Key words: Speechreading, individual differences, cognitive components, speech perception, hearing impairment, compensation.

The dissertation consists of a summary and the following studies:
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Key words: Speechreading, individual differences, cognitive components, speech perception, hearing impairment, compensation.

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Preface

This thesis is based on the present summary and the following studies:


The numbers in parentheses are used in the text to refer to these studies.
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Introduction

Speechreading (lipreading) refers to the ability to understand a speaker's intended meaning primarily by watching his or her lipmovements. Speechreading can take two basic forms; either it is constituted by perception of audio-visual stimuli (i.e. parts of a spoken message are accompanied by sounds), or it is solely based on perception of visual stimuli. The present thesis deals mainly with the latter of these two forms.

A search in the data-bases yields approximately 200 entries involving the terms speechreading or lipreading. These entries cover most areas in psychology, audiology, and speech perception. A comparison with related forms of communication, such as listening or reading, clearly gives the impression that speechreading - as a research object - is a neglected area.

Nevertheless, there are several important reasons for investigating the issue of speechreading. First, although speechreading is usually associated with deafness and hearing-impairment, a visual aspect appears to be involved in almost all listening situations, even for the normal hearing individual. For example, imagine a situation in which there is an asynchrony between heard and seen speech in a film sequence. This is immediately observed by the watcher/listener regardless of the length of the interval between the sound and the corresponding picture (Binnie, Montgomery, & Jackson, 1974; Dodd, 1977). A somewhat more speculative example is that some patients often report to their doctor that they hear better when they wear their glasses.

Visual involvement in normal speech perception has also been demonstrated by a number of researchers (e.g., Cotton, 1935; Campbell & Dodd, 1980; Miller & Nicely, 1955). Typically, these studies use an experimental paradigm with two conditions: In one condition, the subjects are asked to listen to some auditory stimuli
presented together with white noise at a level where about half of the speech signal is intelligible. In the other condition the subjects are presented with the same type of stimuli, but are now allowed to see the speaker's face (Dodd & Campbell, 1980). The results typically demonstrate a significant increase of the intelligibility in the second condition. This outcome is taken as evidence for (a) that there is a visual component involved in normal speech perception, and (b) that this visual component facilitates comprehension of spoken messages.

A second reason for studying speechreading is that it gives an opportunity to study and compare perceptual and cognitive component processes that may display both similarities and dissimilarities with the roles they play in two relatively well-explored language perception forms: listening and reading (Campbell, 1988; Conrad, 1979; Dodd, Oerlemans, & Robinson, 1988; Massaro, Cohen, & Thompson, 1988).

Third, speechreading constitutes a necessary prerequisite for a large number of hearing-impaired individuals in their every-day communication with other individuals, and further, speechreading is one of the cornerstones of auditory rehabilitation (Summerfield, 1983). Speechreading is always important for hearing-impaired individuals, as today's hearing amplifiers are not fully capable of simulating those processes of selective attention necessary for listening to a normal conversation. That is, all sounds (from the talker as well as from the environment) are amplified and transmitted to the listeners. Although there exist attempts with computer-controlled hearing-aid, which intend to amplify only those frequencies that are impaired in the subject, these can reduce, but not eliminate the problem of fast shifting of attention. Thus, an important reason for scientific investigation in this area is its every-day relevance.

A fourth reason for studying speechreading is a consequence of the third; it opens the possibility to study the concept of psychological compensation (Hjelmquist & Nilsson, 1986): That is, speechreading in itself may constitute a compensatory
means because the auditory channel is the primary channel for information intake in speech perception. Hence, it is important to determine to what extent and under what conditions speechreading can substitute for a deterioration in auditory speech perception. Furthermore, it is important to determine which individuals benefit from speechreading. For example, will a group of hearing-impaired individuals improve their speechreading ability compared to a normal hearing group as a consequence of their daily reliance on speechreading, or is structured practice necessary to improve the ability?

Thus, it is submitted that there is ample reason for exploring and examining the relatively new and exciting domain of cognitive and perceptual research: Speechreading.

The process of speechreading: Possibilities and limitations.

In the research literature the terms lipreading and speechreading (sometimes also visual speech perception) are used interchangeably (e.g., Farwell, 1976). Some researchers prefer the term lipreading to emphasize the process of decoding a speaker's lipmovements. Others suggest the term speechreading to indicate that the process involves more than just decoding of lipmovements, such as filling-in missing pieces of information (see Berger, 1972; Jeffers & Barley, 1971; Farwell, 1976, for reviews). In the present thesis, the latter position is taken and the term speechreading will thus be used throughout. This term will also be used when other studies are reviewed, regardless of what term the author has preferred.

Speechreading is not an easy task as only a limited number (approximately about 10-25 %) of all spoken phonemes involve lipmovements visible enough for decoding (cf. Dodd, 1977; Dodd, Oerlemans, Robinson, in press; see Jeffers & Barley, 1971, for a review, and Amcoff, 1970, for for Swedish stimuli). Adding to the complexity, many of these phonemes are hard to distinguish from each other,
expressed in isolation (Woodward & Barber, 1960; Jeffers & Barley, 1971). Thus, it should be almost impossible to solve detective problems by watching the conversation of two persons from a distance, as some Hollywood producers suggest (Summerfield, 1983). There are conditions, though, in which speechreading performance appears to be enhanced: For example, successful performance is optimized at a distance of 1.5 m with a bright illumination (Erber, 1974), with a speaker whose arms and torso are visible (Larr, 1959), and without distractors like beard or moustache (Berger, 1972; Summerfield, 1983). Furthermore, information about the situational context in which the message is uttered improves performance (Garstecki, 1976; Garstecki & O'Neill, 1980; Pelson & Prather, 1974; Smith & Kitchen, 1972), as do syntactic, semantic and pragmatic aspects of the message (Summerfield, 1983). This information is used to anticipate communication and to guide the speechreader's inferences when he/she is filling-in missing pieces of information. Also, speechreading performance improves when the speechreader has the opportunity to take advantage of prosodic elements of spoken language, transmitted by tactile devices (see Weisenberger & Russell, 1989, for a review). However, it is not clear in what kind of speechreading situations this device is most suitable, or which subjects benefit the most from it. This issue is far from explored and understood.

Moreover, comprehension of audio-visually presented speech stimuli might be somewhat less complex as there appears to be an inverse relationship between visual and auditive distinctiveness, such that what is easy to hear is difficult to see and vice versa (Summerfield, 1987; Walden, Prosek, Montgomery, Scherr & Jones, 1977).

The ability to attend to visually presented speech information develops very early in childhood. Dodd (1987) found that children at the age of 19 to 36 months are capable of speechreading familiar words. This result was replicated by Rönnberg (1989a) in a single-case pilot-study. The results are suggesting that children not
only store information about the phonological properties of words, but they also store the visual characteristics of words. That is, speechreading ability is not unique to individuals with a fully developed linguistic competence.

Moreover, results from a study with two stroke patients (Campbell, 1985) demonstrate that a patient with a right hemisphere lesion suffered from problems of face-processing (e.g., to recognize familiar faces), but had no problems in speechreading. The other patient, suffering from a left hemisphere lesion, had no problems of processing faces, but was unable to speechread. Campbell (1987) suggested that the results indicate that speechreading is lateralized to the left hemisphere. Nevertheless, note that there are results from studies with cerebrally intact subjects suggesting that certain aspects of the speechreading skill can also be handled in the right hemisphere (Campbell, 1985).

All in all, although developed in infancy, speechreading is difficult, and cannot replace a normally functioning auditory system as a means for speech perception. However, given optimal conditions, some degree of substitution for the loss of auditory signals may be attained.

Review of the literature: Trends

Although speechreading is a relatively neglected area as a research object, it has been the subject of research activities during a period of 75 years. A first trend that can be identified concerns the attempt to isolate psychological factors that discriminate "skilled" from "less skilled" speechreaders. This is also the issue to which most research efforts have been devoted. A typical approach has been to compute a correlation coefficient between performance on a speechreading test (e.g., Utley, 1946) and scores on a test measuring a psychological variable, which for various theoretical reasons might be related to speechreading performance (Farwell, 1976; Gailey, 1987; Jeffers & Barley, 1971). The dependent measures
in these studies have typically been the number of syllables, words, key-words within sentences, and sentences that the subject can speechread correctly (Squire, 1985). Examples of other dependent measures include the number of words that a subject is able to reproduce in "tracking" connected discourse (DeFilippo & Scott, 1978). On the other hand, variables such as comprehension have typically not been studied. Thus, the operationalization of speechreading skill has been based on the number of linguistic units that an individual is able to speechread and reproduce in written or oral form.

Unfortunately, the researchers in this area have been less successful in isolating the psychological variable(s) that constitute(s) the skill(s). According to Gailey (1987), investigators have repetitiously raised the question: "What are the psychological factors that distinguish "good" from "poor" speechreaders?", from the very first published study on speechreading skill (Kitson, 1915) to more recent work. This, of course, does not imply that researchers have failed to find relationships between a certain psychological variable and performance on a test of speechreading ability. On the contrary, there are numerous examples of variables that correlate substantially with speechreading (see Jeffers & Barley, 1971, for a review). The problem is that these correlations have, as a rule, not been possible to replicate for other investigators (Gailey, 1987). There are a number of possible reasons for the observed inconsistency across studies. Factors such as how speechreading is assessed, the characteristics of the psychological variable(s), and the populations under scrutiny, may contribute to the mixed results.

The second trend is a relatively new one, dating back to the last decade. Here, an incessant number of papers have dealt with experimental problems in speechreading (see Dodd & Campbell, 1987, for a review). Within this domain, two research directions can be identified. One has typically dealt with issues in audio-visual speech perception such as how auditive and visual information is fused (cf. McGurk & MacDonald, 1976, see also Massaro, 1987; Summerfield, 1987, for reviews). In
the second approach, researchers have primarily been interested in how visually presented speech stimuli are represented and coded in short-term memory (see Dodd & Campbell, 1984; 1987, for reviews).

A third trend relates to technical compensation for the hard of hearing. Examples are the development of wrist-worn vibrotactile devices as alternatives to hearing aids (Weisenberger & Russell, 1989), and the evaluation of perceptual capabilities following a cochlear implant (Eisenberger, 1985). Although most studies demonstrate an improvement of speech perception through these devices, it is not clearly established if this improvement is tied to some specific listening condition (i.e., word or syllable decoding, or "tracking" a connected discourse). Also, it is not clear what kind of individual characteristic (e.g., perceptual or cognitive) best promotes visual speech perception.

In sum, research in speechreading have followed three relatively separate lines: One correlational, one experimental, and one dealing with clinical interventions through technical devices.

A selective review of the literature

The review of the literature is selective in two respects: First, it focuses on how individual differences in perceptual and cognitive component processes can explain individual variations in visual speechreading performance, as well as how more complex "variables" such as reading, chronological age, and factors associated with the impairment (e.g., level of hearing loss, onset, or number of years as impaired), are related to speechreading. This means that most studies dealing with the influence of, for example, personality traits (which are few) on speechreading performance, or with audio-visual speech perception, are excluded.

Second, the populations discussed in this review are adults (normally hearing and hearing-impaired, with a post-lingually acquired impairment). In some
instances, other populations (e.g., children and adults with a pre-lingually developed impairment) are included for comparative purposes. Finally, this review also stresses experimental studies dealing with cognitive and perceptual processes in speechreading.

Visual skills related to speechreading performance.
Visual skill has been conceived of as one of the "primary factors" constituting speechreading skill, and also as one of the cornerstones in rehabilitation (cf. the analytic approach, Jeffers & Barley, 1971). However, there appears to be no consensus as to how this ability should be operationalized. According to Jeffers and Barley's definition, visual skill includes factors like perceptual proficiency in detecting and discriminating lip movements, the ability to rapidly perceive speech elements, and the ability to extract peripheral information (e.g., from the face of a talker). However, these factors are only "believed" to be important to speechreading. Jeffers and Barley (1971) reported only a few attempts to investigate the issue empirically, and none of these efforts yielded statistical support. Also, the operationalizations suggested by Jeffers and Barley are based on direct assessments of the skill. Other studies, using more indirect assessments, such as tachistoscopic techniques (Kitson, 1915; O'Neill & Davidson, 1956), or detection of spatial relations (O'Neill, 1951), have also failed to detect any significant relationships between scores on these tests and speechreading performance.

Nevertheless, if we accept decoding of isolated words and syllables as operationalizations of a hypothetical visual skill, as they are "free" from influence from syntactic and pragmatic factors (Brannon & Kodman, 1959; Sudman & Berger, 1971), there is some evidence for the existence of a relationship with other, more complex speechreading stimuli, such as sentences or short stories (e.g., Di Carlo &
Kataja; 1951; Shoop & Binnie, 1979, Utley, 1946; see Gailey, 1987, for a review).

In sum, the picture is far from clear as to how visual skill is related to speechreading. Before the nature of this possible relation is established, a first reasonable step is to decide how this skill should be assessed. Should the assessment be direct or indirect? If a direct assessment is chosen, what kind of dependent measure taps the skill in the most sensitive way? Detection, discrimination, or decoding (Erber, 1977)?

Recoding: the internal speech code and speechreading.
Speechreading, as defined in the present thesis, is a visual task. There is ample evidence that internal speech is involved in short-term/working memory (Baddeley, 1986; Conrad, 1964), reading (Huey, 1908/1968), and thinking (Max, 1937; Vygotsky, 1962; see Baddeley & Wilson, 1985, for a review). With respect to speechreading, this issue was first considered by Stobschinski (1928). His idea was that a large part of the variation in speechreading performance could be explained by the internal "thought-processes" used by the speechreader. However, this reference comes from a secondary source (Oyer & O'Neill, 1985) and information as to whether Stobschinski (1928) actually tested this hypothesis empirically cannot be provided.

Conrad (1979) investigated the role of internal speech in speechreading using a paradigm from the memory literature (Conrad, 1964). The results generated within this paradigm have typically been interpreted as an index of phonological (re)coding in short-term memory. The key feature of the paradigm is to study errors made by subjects in their attempts to recall sequences of consonants. A typical result is that the errors tend to be based on phonological confusions rather than visual, hence suggesting that some form of phonological coding in short-term memory exists. This type of coding strategy also appears to be adopted by congenitally deaf children
despite the fact that they have never been able to hear (Conrad, 1970). When investigating this issue in relation to speechreading, Conrad used a population of hearing-impaired children (age 15-16 years). Further, he made a simple dichotomy in which he assumed that children who made more than 52% phonologically based errors would be utilizing an internal speech code. Three main results emerged: First, there was a relationship between the degree of hearing-loss and the use of an internal speech code. Second, there was a relationship between the ability to speak (rated by teachers) and internal speech. Third, there was a relation between internal speech and speechreading performance.

Although these results are quite informative, more data are needed before we can reach any firm conclusion as to what kind of role the internal speech code serves in speechreading. First, we have to know whether Conrad's results are generalizable to other populations than children. Second, we have to assess whether there is an interaction between type of materials and the use of an internal speech code. For example, it is known from the domain of reading research that the use and access of an internal speech code is more critical for specific parts of a text than it is for other parts. That is, the utilization of an internal speech code appears to vary as a function of text difficulty (Hardyk & Petrinovitch, 1970), word frequency, and level of reading skill (see Wagner & Torgesen, 1987, for a review). We also know that there is some form of direct access route to the mental lexicon (without transformation) for example, when the skilled reader encounters high frequency words in reading (Wagner & Torgesen, 1987). An interesting question is whether there are similar processes in speechreading. Third, it is important to evaluate more qualitative aspects of "internal speech". Here, it may be fruitful to use a less dichotomous dependent measure (e.g., a reaction-time paradigm) than the memory-based paradigm introduced by Conrad (1979).

Using a reaction-time paradigm, in which subjects' task was to make judgements about word homophony, Lyxell and Rönnberg (1989a) demonstrated that there was
no difference between a group of hearing-impaired (acquired deafness) and a group of normal hearing subjects in decision speed. However, there was a difference in decision accuracy such that the hearing-impaired subjects made significantly more errors than the controls. Further, there was a correlation between accuracy and performance on a sentence-based speechreading test ($r(20) = .55, p < .01$) for the hearing-impaired group, but not so for the normal hearing. The speed with which subjects made their decisions was not related to performance on the speechreading test. These results were replicated by Lyxell and Bäckman (1989), using a slightly different test. This result is interesting for at least three reasons. First, the result suggests a relationship between an internal speech code and speechreading, also when paradigms other than memory-based ones are used. Second, it shows that the result is generalizable to other groups than children, and to other groups than those with a congenital hearing-impairment. Third, the result also suggests that there is a difference in how hearing-impaired individuals (with an acquired deafness) process phonologically based information compared to individuals with dysarthric problems, who use more time to execute their decisions than normal controls (Baddeley & Wilson, 1984).

**Short-term memory and speechreading performance.**

Visual short-term memory has been assumed to be one of the most important components for speechreading skill (Jeffers & Barley, 1971; Oyer & O’Neill, 1985). A typical assessment tool has been to correlate performance on a visually presented memory span test (usually a part of an intelligence test consisting of letters and digits) with performance on some speechreading test. The results demonstrate a substantial relationship when deaf and hearing-impaired children serve as subjects (Costello, 1957; O’Neill & Davidson, 1956). For normal hearing adults and hearing-impaired adults the picture is less clear. For these groups, there appears to be no relationship when visually presented digits or letters constitute the
stimuli (O'Neill, 1951). On the other hand, there appears to exist a relationship when objects (presented at the same rate as letters/digits) constitute the stimuli to be remembered (Simmons, 1959).

Using a somewhat different approach, De Filippo (1982) found a relationship between memory for articulated sequences (syllables and sentences) and speechreading performance. Unfortunately, it is difficult to evaluate whether this relationship is based on a correlation between a memory test and a speechreading test, or just a correlation between two speechreading tests, since it is hard to distinguish the actual memory and speechreading tasks from each other.

Note that the distinction between short- and long-term memory is not made in the studies cited above. The reason for this is simply that the distinction was not made at the time when most of these studies were conducted. However, few would dispute that the tasks employed (i.e., memory span) measure short-term memory performance (Dempster, 1981; Watkins, 1977). Also, in the light of recent theoretical advances in the field of short-term memory it is possible to evaluate and elaborate on the conclusions from the results presented from 1950 and a decade onwards.

One way of illustrating this is to examine the dissociation in how digit span performance relates to speechreading for children and adults respectively. Regardless of presentation modality, digit span is usually a good predictor of children's reading performance, but does not predict the fluent adult reader's performance (Baddeley, 1986; Daneman & Carpenter, 1980; 1983). One reason for this is that the memory span is increasing systematically throughout childhood (Baddeley, 1986; Hitch & Halliday, 1983; Hitch, Woodin, & Baker, 1989), and should thus be a more critical component for children than for adults. In addition, there is a theoretical controversy within the field of developmental psychology as to what causes these developmental changes in performance. Some argue that the changes are simply due to an increased capacity (e.g., Pascual-Leone, 1970, Halford & Wilson, 1980), others that it is due to the development of strategies and control
processes (such as, for example, coding processes, Chi, 1978), whereas still others take an intermediate position (Case, Kurland, & Goldberg, 1982; see Baddeley, 1986, for a review).

These different interpretations of development in memory span could be applied to explain why memory span appears to be more critical for children's speechreading compared to adults'. If the children do not possess the capacity to store a certain amount of decoded items, then short-term capacity will probably increase its critical importance as an information-processing bottleneck in speechreading. On the other hand, if we accept the view that development of memory span is due to "more sophisticated control processes and strategies" (Chi, 1978), then a memory coding explanation concerning the relation between memory span and speechreading performance seems most plausible; the critical assumption being that children do not have access to an internal speech code (Conrad, 1979).

Finally, short-term memory processing in speechreading has recently received attention from a number of researchers in related fields. The object of study has been to investigate how speechread information is represented in short-term memory, as well as to compare this representation with written and spoken language representations. A typical paradigm for investigating this issue is to examine how an irrelevant suffix (not to be remembered), presented immediately after a list of words or digits, interferes with recency performance (Crowder & Morton, 1969). If speechread and auditory recency effects have a common source of representation, then the recency effect for speechread lists should be interfered with (i.e., reduced) by an auditorily presented suffix (Campbell, 1987). Support for this hypothesis comes from a number of studies (Campbell, 1987; Campbell & Dodd, 1980; 1984; Gathercole, 1987; Greene & Crowder, 1984). This notion has also been elaborated by Campbell, Garwood, and Rosen (1988, see also Penney, 1989), who suggest that although speechread stimuli share some processing properties with auditorily presented items, they possess some additional unique features. Awaiting further
theoretical precision, the consequence of the pattern of results described is that the theory of a precategorical acoustic storage (PAS, Crowder & Morton, 1969), needs to be reformulated (Campbell, 1987).

**General speed of information-processing related to speechreading performance.**

The speed with which lexical information can be accessed from long-term memory should be an important component in speechreading. However, to my knowledge, this issue has not been investigated in speechreading research (although discussed by Summerfield, 1983). The rationale for its assumed involvement and importance in speechreading is simple. Fast lexical processing of decoded parts of a message will give the speechreader a possibility to free resources for other necessary processes in speechreading. Hunt (1978; 1980; 1985; see also Sternberg, 1985a; b) has proposed that part of the variability in verbal intelligence could be explained by individual differences among individuals in their speed of accessing information from long-term memory. In addition, access speed has proved to be an important component in reading comprehension (Baddeley, Logie, Nimmo-Smith, & Brereton, 1985; Jackson & McClelland, 1979; Palmer, MacLeod, Hunt, & Davidson, 1985). A typical paradigm investigating the putative relationship among access speed, verbal intelligence and reading is to present a pair of letters to which subjects are asked to respond "yes" or "no" with respect to their physical or name identity (Posner & Mitchell, 1967; Posner, Boies, Eichelman, & Taylor, 1969), or to have subjects decide whether a string of letters constitute a word or a non-word (Rubenstein, Lewis, & Rubenstei, 1971).

Using verbal materials, such as letters or letter strings, and relating matching performance to, for example, some reading criterion, would seem to be a straightforward way to assess this relationship. However, it may not be as simple to apply these assessment tools to speechreading, the reason being that the speechreader has to decode relatively (if visible) ambiguous lipmovements from the talker's mouth, as
opposed to letters or strings of letters. This situation is further complicated by the fact that there is no one-to-one relation between the spoken stimuli and their representation in the mental lexicon. Rather, a one-to-many relation seems to hold true for lipread stimuli (Summerfield, 1983). Despite its lack of face validity, the use of letters and words in matching tasks may still shed some light on the speechreading process, as they are assumed to tap some general verbal information-processing speed factor (Cattel, 1971).

Yet another aspect of information-processing speed in speechreading is addressed in studies by Shepherd, DeLavergne, Frueh, and Clobridge (1977), Shepherd (1982), and Samar and Sims (1983, 1984). The objective of these studies was to investigate how different indices of visual evoked response times (VERs) to light flashes were related to speechreading performance. Shepherd et. al. (1977) found surprisingly high correlation coefficients ($r = -.90 - -.91$) between one index of VER (VN 130) and performance on a speechreading test (Utley, 1946). Based on a test-retest paradigm, Shepherd (1982) replicated this result (although with a lower, but still substantial correlation coefficient, $r = -.61$ to -.89), and also provided results suggesting that the relationship is reliable over test sessions. The finding was again replicated by Samar and Sims (1983), with a somewhat lower coefficient ($r = -.57$). They could also demonstrate the impact of a very early VER parameter (VF 16) on speechreading ($r = -.60$). According to Samar and Sims, the VF 16 reflects individual differences in general sensory processing speed. In a follow-up study, Samar and Sims (1984) replicated their initial finding that VF 16 was related to speechreading performance ($r = -.73$). However, in this study the relationship was restricted to hearing-impaired men.

In sum, these results suggest that speechreading performance is highly dependent on the speed of firing of visual neurons, as indexed by the VER parameters. However, it may be wise to raise some additional questions before we can draw any safe conclusions about the relationship between VER parameters and speechreading
performance (see also Massaro, 1987). For example, does this relationship exist for other speechreading tests than Utley’s (1946), and is it related to other forms of communication? And, are the results tied to specific groups of individuals and to sex?

**Inference-making ability and speechreading performance.**

A necessary operation for the speechreader is to fill-in missing pieces of information, as it is usually not possible to extract all information by watching the lipmovements only. Lyxell and Rönnberg denoted this process guessing (1987a, b) or inference-making (Lyxell & Rönnberg, in press a; Rönnberg, Arlinger, Lyxell, & Kinnefors, in press). Other labels include perceptual closure (Bode, Nerbonne, & Sahlstrom, 1970; Sanders & Coscarelli, 1970; Tatoul & Davidson, 1961), conjectural closure (Simmons, 1958), cloze ability (Williams, 1982), problem-solving (Gailey, 1987), and synthetic ability (Jeffers & Barley, 1971). Despite the terminological disagreement there is a significant relationship between performance on tests measuring the ability to fill-in missing parts of information and speechreading performance, as demonstrated in all studies cited above. Although the results from these studies indicate the existence of such a relationship, further information is needed. For example, we need to know more about the precise nature of inference-making in speechreading. Further, although inference-making may be a critical skill in speechreading we do not know for which aspects of speechreading it is critical. For example, is it related to all kinds of speechreading situations, or, as suggested by Gailey (1987), is it only related to those situations which involve a certain degree of linguistic complexity? Support for the latter position comes from studies by Lyxell and Rönnberg (1987a, b, in press), who demonstrated that the skill to fill-in omitted words in sentences was related to speechreading performance only when relatively long sentences with a low level of contextual support were presented.
Verbal ability and speechreading.

It is presumably important that the speechreader is in possession of linguistic skills necessary to meet the requirements inherent in a speechreading task. This ability is usually assessed by the verbal parts of intelligence tests, and most often, by the tests of vocabulary size. Vocabulary size is usually a good predictor of general verbal intelligence (Hunt, 1985; Matarazzo, 1972). When this ability has been related to speechreading performance the pattern suggests that there is a significant correlation, given that the population consists of deaf and hearing-impaired children (Quigley & Frisina, 1961; Lowell, 1960). However, no relation has been reported for the populations of adult hearing-impaired and normal hearing subjects (O'Neill, 1951; Simmons, 1959; Wong & Taaffe, 1958). One way of summarizing these results is that verbal ability is not critically related to speechreading performance, if the verbal ability is within a normal range. A similar pattern of results has been demonstrated for the relation between general intelligence and speechreading, where similar explanations also have been offered (Oyer & O'Neill, 1985; see also reviews by Conrad, 1979; Farwell, 1976; Mogford, 1987).

Reading ability and speechreading skill.

It has been suggested that the reader as well as the speechreader has to use a combination of visual linguistic cues to interpret the meaning of a message (Williams, 1982; see also Buswell, 1920; Goodman, 1976; Jeffers & Barley, 1971; Popelka & Berger, 1971). A significant relationship between reading ability (measured by some standard test) and speechreading performance has been reported for hearing-impaired and deaf children with a prelingually developed hearing-impairment (Simmons, 1959; Utley, 1946), whereas no such relation exists for the populations of individuals with a postlingually developed impairment and normal hearing subjects (O'Neill, 1951; O'Neill & Davidson, 1956). Williams (1982) found that good readers (normal hearing high-school students) were either "good" or
"poor" speechreaders, whereas poor readers were more likely to be "poor" speechreaders. She concluded by stating that "good" speechreaders and readers do not engage in a word-by-word reading, rather they use a combination of linguistic and visual cues to interpret meaning. However, results from a number of contemporary studies in the reading literature, suggest that one difference between good and poor readers is that the good readers rely more on a word-by-word reading strategy (e.g., Stanovich, 1981, West & Stanovich, 1978), whereas poor readers (with poorer decoding functions) have to rely more on the contextual information given. Nevertheless, Williams established a relationship between some reading-related tasks (cloze ability, eye-voice span) and speechreading.

In sum, there appears to be no relation between reading and speechreading when the population comprises adults (normal hearing and hearing-impaired), and when reading is assessed by total performance on some standard assessment of reading ability. Despite this absence of relation, there might still be some relation if reading is split up into its subcomponents, as indicated in Williams' (1982) study.

Listening and speechreading performance.

The other form of communication, relevant to a comparison with speechreading, is listening. Given normal conditions, listening to speech is an easy task if the listener is not hearing-impaired, at least if we compare discrimination of stimuli in listening with discrimination in speechreading. Individual differences in listening are not readily observable (Massaro, 1987), and a failure to reach perfect performance in listening tasks might (at least in the worst case) indicate that the individual is suffering from some more central brain damage (for example, Wernicke's aphasia). Hence, there seems to be a relatively minor gain in studying the concept of "listening skill". Also, there is no tradition of studying individual differences in the field of auditory speech perception. Rather, researchers in this
area have devoted their efforts to investigating the general process of auditory speech perception (see Frauenfelder & Tyler, 1987, for a review).

**Chronological age and speechreading.**

A number of studies have examined the effect of chronological age on speechreading performance (Ewertsen & Nielsen, 1971; Farrimond, 1959; Goetzinger, 1963; Lyxell & Rönnberg, in press b; Pelson & Prather, 1974; Rönnberg, 1989; Shoop & Binnie, 1979). Common to these studies is that a general decline in speechreading performance as a function of increased age has been found (see however, Simmons, 1959, for an exception). Lyxell and Rönnberg (in press b) investigated whether older subjects can, as in listening tasks (Cohen & Faulkner, 1983; Cohen, 1987), compensate for a general decline by taking advantage of contextual cues. The result indicates that there is no difference between younger and older subjects in their relative utilization of contextual information in speechreading. A proposed explanation from the perspective of normal aging and reading, is that it is easier for young subjects to reach their functional performance ceiling level of performance in reading, and thus, the addition of an extra contextual information gives no (or only a minor) enhancement (Bäckman, Mäntylä, & Herlitz, in press). However, older subjects need this extra information to reach their functional ceiling. Speechreading, on the other hand, constitutes an extremely difficult task, and to reach a functional ceiling level without extra contextual information would require an extraordinary skill. Therefore, extra contextual information enhances performance across the entire age range.

According to the literature on cognitive aging, two factors appear to be strongly associated with cognitive impairment due to increased age; working memory capacity (Gick, Craik, & Morris, 1988; Light & Anderson, 1986; Morris, Gick, & Craik, 1988) and the speed with which information can be processed (Cohen, 1987; Salthouse, 1982; 1985b). These factors were investigated in speechreading by
Rönnberg (1989b), who used four different classes of cognitive tasks (short-term memory tasks, tests of long-term memory access, verbal tests, and tests of visual speech decoding ability). Two factors emerged as responsible for discriminating young from old subjects, as well as skilled from less skilled speechreaders: visual speech decoding ability and a cognitive speed factor (as operationalized by the level of asymptote in the serial-position curve, cf. Salthouse, 1985b). First, speech-decoding was related to age decrements in speechreading in the same way as for listening (cf. Cohen, 1987). Second, rehearsal speed, which is assumed to be one of the factors responsible for deterioration in cognitive performance in old age (Salthouse, 1985b) showed a similar relationship to speechreading. Thus, most other studies where cognitive performance has been related to a criterion, and where criterial performance has been found to decrease as a function of age, were replicated.

In sum, chronological age affects speechreading performance, such that elderly subjects (older than 60) are inferior compared to younger speechreaders. It is important to find the cognitive basis for this general decrement, and also to find conditions in which older subjects can compensate for their deficit. The study by Rönnberg (1989b) constitutes a starting point with regard to this issue. And above all, studies investigating the issue of chronological age and speechreading are important and highly relevant, as hearing-impairment is a problem tied especially to the population of older adults.

Hearing-impairment and speechreading performance.

Intuitively, it seems reasonable to assume that a group of hearing-impaired individuals (i.e., with the impairment developed post-lingually) should outperform a group of normal hearing controls on speechreading tasks. The rationale for this assumption is simple and straight-forward: As a function of their impairment, impaired subjects should have to rely on speechreading to a higher extent in their
every-day life communication than their normal hearing counterparts. However, a somewhat counterintuitive result is that there is no difference between hearing-impaired (post-lingually acquired impairments) and normals (Erber, 1972; Jerger & Speaks, 1986; Clouser, 1976; 1977; Conrad, 1977; Lyxell & Rönnberg, 1987a, b, in press a; Mogford, 1987; Rönnberg & Lyxell, 1986; Rönnberg, Öhngren, & Nilsson, 1982; 1983). Other indications, of no handicap-specific effects in speechreading, come from studies in which the degree of hearing-loss (assessed by pure-tone audiograms over selected frequencies for the "better ear"), and number of years as hearing-impaired, have been related to speechreading performance. None of these two factors show a significant relationship with speechreading performance (Erber, 1972; Lyxell & Rönnberg, 1987b).

However, these factors must be regarded as rather crude measures of the impairment, at least in relation to speechreading. Detecting the presence of a tone presented at different frequencies may be relevant for audiological purposes (e.g., for the fitting-in of hearing-aids), but it is questionable whether it is relevant for speechreading, as it does not tell us very much about the individual's ability to process speech-based stimuli. Number of years with an impairment might be an untenable indicator of the nature of the impairment, as there is a large individual variation with respect to other factors that determine how the impairment is acquired (i.e., sudden or progressive), and with respect to which frequencies that are impaired.

In sum, there is no empirical support for the notion that hearing-impaired individuals are more skilled in speechreading than normal hearing individuals. Therefore, skill in speechreading does not seem to develop spontaneously as a function of an increased need to speechread in every-day life. This could also be taken as support for the proposition that no compensatory effects exist in speechreading. However, it would be somewhat premature to adopt this proposition. Even though impaired subjects and controls may perform similarly in speechreading tasks, it is
still possible that the hearing-impaired rely on a different set of perceptual and
cognitive components, or that they use different strategies (cf. Salthouse, 1984, for
a discussion of strategy differences between young and old typists).

Although speechreading skill does not develop spontaneously, many studies
report that structured practice or training improves the subjects' ability to
speechread (e.g., Binnie, Jackson; & Montgomery, 1974; Black, O'Reilly, & Peck,
1963; Crawford, Dancer, & Pittenger, 1986; Hutton, 1960; Jacobs, 1975; Rosen &
Corcoran, 1982; Walden, Montgomery, Scherr, & Jones, 1977). These studies
demonstrate a relatively wide range of improvement following practice (3 %,
Hutton, 1960, to 28 % Jacobs, 1975). However, it is not clearly established which
subjects improve most from practice, those with high pre-test scores, or those with
low (Crawford, Dancer, & Pittenger, 1986; Rosen & Corcoran, 1982; Walden,
Montgomery, Scherr, & Jones, 1977), or what kind of individual characteristics are
most critical for the level of improvement.

Summary and critique

The present review has focused on two trends of research in speechreading:
Individual differences in speechreading and the experimental investigation of
cognitive and perceptual processes in speechreading.

The work reviewed with respect to the first of these two trends does not provide a
satisfactory answer to the question of which psychological variables predict skill in
speechreading. Rather, substantial correlation coefficients may exist between a
particular psychological variable and performance on a speechreading test, but this
relation is too often tied to cohort factors (for example, whether the hearing-
impairment is developed pre- or post-lingually).

Still, the results discussed appear to have some generality across studies. First,
there is no significant relation between those factors associated with the hearing-
impairment and speechreading performance. Second, skilled performance in inference-making appears to be significantly related to success in speechreading across all groups examined, and across different ways of assessing speechreading performance, and for different operationalizations of the ability.

Although this relation appears to have replicability, the process of speechreading is a multi-componential process which is not possible to capture accurately by investigating one single class of tasks (Carr, 1981). It is rather obvious that more information is needed about the nature of the speechreading process itself, and about how individual differences in information-processing subskills relevant for speechreading are associated with skilled speechreading, before we can make predictions about an individual’s speechreading ability, and construct training programmes.

There are a number of plausible reasons why this state of affairs exists. The first is a rather obvious one: Speechreading is a relatively neglected area as a research object. This is especially apparent in at least two different ways: (a) Potentially relevant and important fields in speechreading are unexplored. The concept of lexical processing speed is an example of this neglect. Indices of lexical speed has proved to be a good predictor general verbal ability (Hunt, 1978; 1980; Hunt, Lunneborg, & Lewis, 1975) and reading (Jackson & McClelland, 1979; Fredericksen, 1982; Baddeley, Logie, Nimmo-Smith, & Brereton, 1985), and should intuitively be a critical component process for speechreading as well. This is because the temporal demands are even more emphasized in speechreading than in reading. Other relevant fields have merely been touched upon. The concept of visual skill constitutes a good example of this. (b) Some potentially important aspects of speechreading skill have been treated without sufficient theoretical consideration, as, for example, the concept of short-term memory capacity.

A second reason for lack of success to find reliable predictor variables to speechreading performance stems from the populations used. In most studies on
speechreading, a group of hearing-impaired subjects are included and (sometimes) compared with a group of normal hearing subjects. The problem is that each group of subjects carry their own unique set of cohort factors, not decisive for other groups' speechreading performance. Thus, it is difficult to make general inferences about the source of individual differences in speechreading ability based on one group of hearing-impaired subjects' performance.

A third possible reason is the variability of the speechreading tests used. Most of the studies reviewed involve a correlational approach. In these studies, speechreading is either assessed by some speechreading test constructed by the investigator himself, or by some clinically well-established speechreading test (e.g., the Utley speechreading test, 1946). However, these tests do not include any systematic variations of the stimuli. An implicit assumption among most test constructors appears to be that the process of speechreading is invariant across all types of speechreading stimuli. However, as recently demonstrated by Gailey (1987) in a factor analytic study, the process of speechreading consists of at least two types of processes; one associated with the process of extracting visual information from the talker's lip movements, and the other associated with problem-solving aspects (i.e., inferences, Heider & Heider, 1940; Risberg, 1979). Hence, the process of speechreading is not a unitary process, but consists of a number of subprocesses, each with a unique set of task-demands on different cognitive components. A speechreading test that does not appreciate this complexity may constitute an untenable measure of the molar ability. The fact that most speechreading tests suffer from this shortcoming, may explain why most psychological variables are not correlated with speechreading performance. A further complication is that the acceptance of these tests, as reliable and valid measurements of speechreading is merely a function of how frequently they are used for assessment purposes not for other more pertinent reasons (e.g., psycholinguistic reasons, Gailey, 1987, p. 120).
Yet another reason for the lack of progress is that much of the work reviewed above has been carried out to find predictor variables for speechreading success, with the purpose of improving rehabilitation techniques and programmes, not to expand theory. However, most of the variables are chosen on intuitive grounds, rather than on any existing psychological model (Farwell, 1976; Gailey, 1987). The reason for this is simple: No such model of general acceptance has yet been proposed.

The present studies

In the empirical section of this thesis an attempt is made to meet some of the criticism raised in the preceding section. The purposes of the empirical studies are (1) to study perceptual and cognitive correlates to individual differences in speechreading, (2) to investigate some specific aspects of the nature of the speechreading process, and (3) to investigate whether hearing-impaired individuals can compensate for their hearing-losses.

First, we will examine how performance on different perceptual and cognitive component processes are associated with speechreading skill. This means that some potential relationships will be investigated with component processes that previously have failed to show any relationship with performance on various speechreading tasks. However, the approach taken here is different from most other efforts. In the present studies, a class of tasks of one particular component process are employed, where each task is assumed to tap some unique feature of the component. Thus, the adopted strategy is broader than the previous ones.

Second, the speechreading tasks used differ somewhat from previous tasks reported in the literature, in the sense that they do not represent clinical tests used for evaluation purposes. Also, two types of speechreading tests are employed, each taxing rather different aspects of speechreading: One word-discrimination/word-
decoding task, in which the task is to discriminate words within word-pairs as being the same or different. The second task is a sentence-based speechreading test. The intention with these tasks is twofold: To cover relatively broad aspects of speechreading, thus allowing for the study of molar as well as molecular aspects of speechreading performance. This was also accomplished by using tests in which a number of factors were explicitly varied. In the word-discrimination and word-decoding tests two variables were varied: The interval between the first and the second word, and type of lure. For the sentence-based speechreading test, two variables were varied: The contextual information, accompanying the sentence to be speechread (Garstecki, 1976; Garstecki & O’Neill, 1980; Lyxell & Rönnberg, 1987a, b; Pelson & Prather, 1974) and sentence length (Clouser, 1976; 1977; Lyxell & Rönnberg, 1987a, b).

Third, speechreading performance of hearing-impaired and normal hearing subjects was compared. This comparison was made despite the fact that the literature has not provided us with any examples of differences in speechreading performance when a group of hearing-impaired (with a post-lingually developed impairment) and normal hearing controls have been compared. The reason for still using these two groups is twofold. First, in most related studies, only a certain group’s molar performance has been investigated. In the present series of studies the groups’ molecular speechreading performance was investigated. Second, although the groups may perform on par with each other on a molar as well as a molecular level, there could still be a difference between the groups in how they rely on different component processes critical to performance. A similar claim could be made for the present inquiry of differences between "skilled" and "less skilled" speechreaders. Such an approach could, for example, be used to detect different speechreading strategies used by the two groups. Overall, the comparison between an impaired group of subjects and normal controls is based on the assumption that hearing-impaired individuals are "experienced" speechreaders, whereas normal
hearing individual subjects are "naive" speechreaders. Thus, an improved performance, or the use of a different strategy for the impaired group vis-a-vis normal controls, might indicate some form of psychological compensation.

A tentative model

The model is based on the assumption that at least a minimal set of different perceptual and cognitive component processes are involved in speechreading. This assumption emanates from the presented research in the summary on speechreading, speech perception, and reading, and indeed, from intuitive reasoning that certain component processes should influence the outcome of the information-processing task which constitutes speechreading.

The model takes as its starting point the empirical fact that there is only a limited number of phonemes perceptually available to the speechreader (cf. Berger, 1972; Jeffers & Barley, 1971). From a perceptual perspective, such as Gibson's (1979), it is quite possible to argue that, at least in principle, sufficient information for perfect visual discrimination should be available. However, the motor apparatus may not produce this information, or the perceptual system may not be tuned fine enough to pick up this information from speech gestures. The latter possibility seems more plausible in view of the fact that speech gestures are aimed at producing discriminable sounds, not discriminable lipmovements.

It is thus necessary to decode and discriminate as much as possible of the lipmovements available to the speechreaders. This information can be used for further, relative to decoding, higher-order processing of the spoken message. Moreover, the input is in a visual format and, accordingly, a transformation from a visual input format to an auditory code may be necessary. Given that this transformation is an important component process, it is also obligatory that it can be executed relatively quickly. This makes it possible to allocate processing
resources to other parts of the speechreading process. Furthermore, it is assumed that the decoded lipmovements have to be stored in some type of temporary short-term memory, while simultaneously new fragments of the message have to be decoded. At a given point in time, the decoded and the stored information can then be used for disambiguation of ambiguous parts of the message, and for filling-in missing parts of the message. This collective processing takes place under a relatively short period of time, and hence, it is decisive that the speechreader has the capability to execute these processes rapidly during the allotted time. Finally, as the components and processes described above are verbal in nature, it seems necessary that the speechreader has a sufficient understanding of language and language processes in order to master the language requirements inherent in speechreading.

The model as it stands does not distinguish between serial or parallel processing, nor does it make any predictions as to which variables are the most powerful predictors of speechreading success. It rather points out which information-processing components are necessary for speechreading performance.

**Summary of empirical results**

The empirical section of the thesis consists of four papers. A general strategy across all papers has been to relate classes of component processes to a sentence-based speechreading test (and to a word-discrimination/decoding task in Study 1), and to examine how performance on certain components within a particular class relates (generally or interactively) to speechreading performance (see Palmer, McLeod, Hunt, & Davidson, 1985, for a similar approach in the reading research area). All components in the tentative model, but verbal ability and the recoding component will be studied. In all studies, a group of hearing-impaired and normal hearing subjects will be compared. This comparison will focus on speechreading
performance and performance in the component processes, as well as how these two relate to each other.

Study 1.

The purpose of Study 1 was to investigate the relationship between speechreading performance, cognitive function, and visual evoked response potentials (VEPs). The basic hypothesis was that visual-neural firing speed was of critical importance to speechreading. The point of departure for this study was the surprisingly high correlation coefficient ($r = -.90 - -.91$) reported by Shepherd et al. (1977) between one aspect of visual evoked potentials (VN 130) and performance on the Utley (1946) speechreading test. The result was replicated (although with lower correlation coefficients) by Shepherd (1982) and by Samar and Sims (1983). In addition, Samar and Sims (1983) demonstrated that a very early VEP parameter (VF 16) was related to speechreading. In a follow-up study Samar and Sims (1984), were able to replicate the Shepherd et al. finding only for hearing-impaired men. The result as such might cast some doubts on the VN 130 as a straight-forward predictor of speechreading success initially assumed. The results also demonstrated a relationship with a test of spatial relations, but not with a test of abstract reasoning.

Study 1 was designed to further explore the nature of this relationship. Specifically, three aspects were of interest. First, to test the generality of the results a larger sample of speechreading (also sign-reading) tests varying with respect to contextual elements was used. Second, the relationship between cognitive components and VEPs was further explored. In this study, a broader set of cognitive tests were employed than in the Samar and Sims (1984) study. The tests were chosen on the grounds that they have previously been found to be associated with speechreading. In addition, speed of processing and short-term memory capacity were emphasized in this study. Third, to test whether the results were group
dependent (as suggested by Samar & Sims, 1984), four groups with different hearing status were tested.

The results of Shepherd et al. (1977, 1982) and Samar and Sims (1983), indicating that VN 130 is an excellent predictor of speechreading performance, were not replicated in the present study. This result applies to all speechreading conditions in the study. However, there was a relation between VEPs and speechreading performance, in that the peak-to-peak amplitude (VN 130/P 200) was related to some conditions in the visual word-discrimination test (i.e., the long interval condition and the decoding condition). It was hypothesized that the amplitude parameter indicates a relatively short-lived visual-neural memory trace (Näätänen, 1986). This trace was assumed to be critical for these two test conditions and not for the complementary conditions for two reasons. First, a weak memory trace has probably not started to decay during the short interval condition. Second, the visual trace is not important unless given the opportunity to interact with auditory representations before the discrimination of the second word. Also, it was demonstrated that the VEPs (i.e., VN 130 and P 200) were related to various kinds of cognitive processing (physical matching and working memory span). These data extend those of Samar and Sims (1984) in that we found a relation between VEPs and cognitive tests which are related to speechreading performance, and not just to cognitive functions in general.

In sum, although we did not replicate the previously reported results, the results indicate that the amplitude parameters of the VEPs are related to a certain aspect of speechreading (word-discrimination), and that the speed parameters relate to certain cognitive functions.

Study 2.

The purpose of Study 2 was to focus on three specific aspects of visual speech processing in speechreading. First, we examined how two visual speech processing
tasks (word-decoding and word-discrimination) relate to sentence-based speechreading. To investigate this, a same-different word paradigm was employed, in which the subjects' task was to judge whether two presented words were the same, or not. In one of the conditions, the first word in the word-pair was presented with sound (bi-modally), whereas in the second condition it was presented without sound (uni-modally). It was assumed that in the uni-modal condition the subjects should be more geared towards discrimination of the second word (i.e., comparing two sets of visual features), whereas the inclusion of sound in the bi-modal condition would bias processing towards lexical decoding of the second word.

Given a relationship between sentence-based speechreading and word-decoding/discrimination is established two principal outcomes were expected: One general and one interactive. It is hypothesized that a general relationship between word-decoding and/or word-discrimination and sentence-based speechreading would indicate that this particular skill may be regarded as an input system operating as an encapsulated module (Fodor, 1983); fast, direct and independently of higher central information processing. An interactive outcome was expected if one accepts that there may be speechreading conditions in which other component processes (e.g., inference-making) may be more dominating than word-decoding/word-discrimination.

A second purpose was to examine the nature of visual speech processing in speechreading, and specifically, to investigate whether there exists processing parallels between visual and auditory speech perception. This was accomplished by means of an error analysis in the word-decoding/discrimination tests. Support for a similarity assumption would be gained if the errors made on either of the tests were tied to the initial phonetic characteristic of the spoken word (Marslen-Wilson, 1987). A final purpose of Study 2 was to investigate possible effects of hearing-impairment on word-decoding/discrimination, and how it relates to speechreading.
There were three main results in this study. First, there were no differences between groups on neither the word-decoding/discrimination tests nor on the sentence-based speechreading test. For the word-decoding/discrimination test, this applied to quantitative as well as qualitative (i.e., error) analyses. It was argued that the data pattern makes it difficult not to conclude that there is no spontaneous compensation effects in speechreading, as an average of 27 years of impairment was not sufficient to cause any improvement in speechreading compared to the normal hearing group.

Second, the results also displayed a dissociation, such that skilled performance on the word-decoding test, but not the word-discrimination test, was related to performance on the sentence-based speechreading test. Further, the skill variable did not interact with any of the conditions in the speechreading test. The results suggest a specification of the visual feature extraction ability, proposed by Gailey (1987) as one of two component processes critical for successful speechreading performance (the other being an inference-making related component). That is, our data suggest that a visual-to-lexical processing route of the words has to be established. It is not sufficient with a mere visual-to-visual comparison.

Moreover, it was proposed that the word-decoding test may be viewed as an operationalization of a word-processing module in speechreading. Three arguments are raised to support this assumption. (1) The lack of interactions indicate that higher levels of processing only have access to the outcome of the input module. (2) The dependency of the initial phonetic characteristic of a word suggests a priority to bottom-up processing, which is one of the more prominent features of modular processing. (3) The lack of interactions with the group-variable also suggests that the input module was primed to the same extent in both groups in the decoding condition; a certain level of hearing is obviously necessary, but the level of hearing loss which the subjects in the study displayed, was sufficient to trigger lexically induced word-decoding.
Finally, the results suggest that there are processing similarities between auditory and visual word recognition (Marslen-Wilson, 1987). That is, auditorily and visually presented words seem to follow the same time-course in the recognition process. However, it was also argued that it would be unwise to overemphasize the significance of the cohort theory of spoken word recognition (cf. Marslen-Wilson, 1987) for speechreading. That is, very few phonemes are in fact visible in speechreading, and they are not necessarily tied to the initial part of the word; still they are possible to speechread. It was therefore argued that a theory of visual speech perception must include the possibility to correct for misfed information later on in the word recognition process.

**Study 3.**

In Study 3, one purpose was to further elaborate the concepts of inference-making skill and working memory capacity, and how they relate to speechreading performance. Whereas most studies only demonstrate a general relationship between inference-making skill and speechreading performance, Lyxell and Rönnberg (1987a) were able to qualify this relation. In short, their results indicated that skilled inference-making was critically related to different speechreading situations, suggesting that speechreading skill is not a unitary skill. However, as Lyxell and Rönnberg included speechreading support in some parts of their inference-making test, the results are not free from the criticism that the relation, as such, is based on a rather trivial correlation between two speechreading tests. In Study 3, the replicability and generality of these findings were investigated using tests of inference-making ability without speechreading support. Note also that the speechreading test is somewhat different than the tests used by Lyxell and Rönnberg (1987a).

Working memory capacity was assessed with a reading span test (Daneman & Carpenter, 1980; Baddeley, Logie, Nimmo-Smith, & Brereton, 1985). This
assessment was used to measure simultaneous storage and processing of information in working memory, and should be contrasted to traditional span tasks, which are assumed to tap the storage component only.

A second purpose of the study was to follow up the trend, existing in the literature that hearing-impaired subjects perform slightly better when the speechreading task is accompanied by contextual information, whereas they perform on par with normal hearing controls when no such information is present (Garstecki & O'Neill, 1980; Pelson & Prather, 1974). In Study 3, this hypothesis was further explored using a more specific contextual cue than in previous studies.

However, the results yielded no differences between the two groups on any of the tests used. For the speechreading test, this implies that we replicate most other studies investigating the same issue. Further, an examination of the simple correlations reveal that both tests of verbal inference-making ability were significantly related to speechreading performance, which is also a replication of previous results. However, a somewhat counterintuitive result was the absence of relation between performance on the reading span test and speechreading. It was speculated that more complex speechreading stimuli may have altered this picture.

To assess the relative contribution of these tests to speechreading ability, the variables were entered into a regression equation. Here, only the SCT (sentence-completion test, as one operationalization of inference-making) accounted for a significant proportion of the variance. However, when SCT performance was used as a dependent variable, both performance on the WCT (word-completion test, as a second operationalization of inference-making) and on the reading span task accounted for a significant proportion of the variation. The implication is that even if there is no (or only a weak) direct relationship with speechreading, there might still be a relationship, although in an indirect hierarchical fashion.

Finally, performance on the SCT, in relation to speechreading performance, was examined in more detail. The results demonstrated a significant main effect of SCT-
skill, and a significant SCT-skill by contextual cue interaction. Further examination of the interaction revealed that it was the less skilled group's performance in the condition without contextual information that was responsible for the significant interaction. That is, less skilled subjects performed significantly lower in the no-cue condition, whereas no such difference occurred for the skilled group.

One conclusion is that inference-making is an important component process in speechreading, thus replicating most other studies in this area. However, the specific contribution from the Study 3 is that we can point out that inference-making in speechreading is rather task-specific, and that a certain degree of contextual compatibility has to be met between the inference-making task and the speechreading test in order to establish a significant relationship. A second conclusion is that one difference between skilled and less skilled inference-makers appears to be that the former are better able to pick up relevant and important information from rather general contextual information. A third conclusion is that skilled inference-making comprises a number of subcomponents, two of which may be working memory capacity and context-free inference-making.

A final result is that we again could demonstrate that there are no differences in speechreading performance between groups of hearing-impaired and normal controls. This also applied to speechreading conditions in which, relative to other studies, specific contextual cue information accompanies the task. Combined with other results in the study (i.e., no relation between speechreading performance and level of hearing-loss, as well as number of years as impaired) this suggests that speechreading skill is not associated with the impairment itself; rather it may be predicted on the basis of subject-related perceptual and cognitive abilities.

Study 4.

One purpose of Study 4 was to elaborate on how elementary information-processing tasks relate to sentence-based speechreading. Specifically, we were
interested in two classes of information-processing tasks; short-term/working memory and speed of lexical access. These two tasks were chosen on the following grounds: Given that certain aspects of visual feature extraction ability (see Study 2) and inference-making ability (see Study 3) are tied to sentence-based speechreading ability, it is also reasonable to assume that also other component processes must come into play. For example, as suggested in Study 3, it is necessary that the speechreader can hold decoded fragments of a message in a temporary short-term memory, until sufficient information has been assembled to make an inference possible. However, performance on the short-term memory task (reading span) used in Study 3, did not relate directly to performance on the speechreading test. In Study 4, the nature of the relationship between short-term/working memory and speechreading was further investigated using a broader range of short-term memory tasks, ranging from relatively passive storage (recency) to more active processing and storage of verbal stimuli (reading span, cf. Daneman & Carpenter, 1980; Baddeley, 1986). Also, the issue whether indices of long-term memory (the primacy and the asymptote level of the serial-position curve) might be related to speechreading was addressed.

A second class of component processes examined in this study was that of long-term memory access speed. This process has not previously been investigated in the area of speechreading. One obvious reason for investigating this process is that speechreading requires a rapid on-line processing of information. For example, the speechreader can not, as opposed to the reader, control the rate of information input. To investigate this putative relationship between lexical access speed and speechreading performance, four different tasks were used, each differing in complexity, from relatively simple matching of physical characteristics (Posner & Mitchell, 1967) to decision-making as to whether a word is a member of a certain category (Hogabom & Pellegrino, 1978). Possible relationships between these tasks and sentence-based speechreading were evaluated. Furthermore, to assess the
relative contribution of these two classes of variables, as well as inference-making and word-discrimination, a variety of multiple regression analyses were carried out.

The results demonstrated no significant direct relationship between performance on the short-term/working memory indices and speechreading. This constitutes a replication and an extension of results reported by Lyxell and Rönnberg (in press a), since we can demonstrate this to be valid for a broader range of memory tasks.

A novel finding is that we can demonstrate a relationship between speed of information-processing and speechreading performance. This relationship is indexed in two types of tasks. First, by performance on the lexical decision task, where the subjects are required to rapidly access verbal information from their long-term memory. Second, by the level of asymptote, which may be conceptualized as a relatively general index of "mental tempo", as it is a reflection of the time needed per rehearsal (Salthouse, 1985a, b; Rönnberg, 1989). Thus, the results extend Gailey's proposed two-process model (i.e., involving the direct predictors of feature extraction and problem-solving) of speechreading in general, as the results also indicate that information-processing speed is an important direct predictor of speechreading.

Moreover, the results from the regression analyses suggest that performance on the word-discrimination task, the level of asymptote, and lexical decision speed each accounted for a significant portion of the variance in the speechreading task. Further, the results imply that performance on a certain component process might relate to speechreading in two different ways; either directly or indirectly. Examples from the present study of component processes that relate directly to speechreading are information-processing speed and word-discrimination. An indirect relationship is constituted by, for example, performance on the reading span test, as it is related to a test which is in turn directly related to speechreading performance.
The results from this study, together with previous results (see Lyxell & Rönnberg, 1987a, b, in press a), also suggest that it is possible to classify the relationship between performance on a certain component process and speechreading into either a general or a specific relationship. A specific relationship is indicated when a certain component process is critically related to a certain aspect (i.e., condition) of the speechreading process, and, consequently, a general relationship is established when performance is tied to all speechreading conditions.

In sum, the results suggest that speechreading skill is composed of a number of different components, each related to speechreading with a varying degree of generality, and located at a certain level in a hierarchical structure behind the skill.

Finally, again it was demonstrated that hearing-impaired subjects do not develop any superior speechreading skill compared to normal hearing individuals. In this study, we can also demonstrate this by a population with a somewhat broader range of hearing loss than in previous studies. Also, there was no difference in performance on the component processes investigated, or how they relate to speechreading. Thus, it was suggested that speechreading skill is governed by other factors than those associated with the impairment.

**Concluding Discussion**

The results of the present thesis can be summarized in three main points: (a) sentence-based speechreading skill is multi-dimensional and composed of a number of different perceptual and cognitive components, (b) the nature of the process of speechreading shares some temporal properties with that of spoken word recognition, and (c) there is no difference in speechreading performance, or in the reliance on the component processes that support speechreading skill due to hearing status. The following discussion will in turn focus on these issues in more detail.
An examination of the overall pattern of results shows that, although some aspects of all component processes are always involved to some extent in speechreading, they relate to speechreading performance in different ways; either directly or indirectly. A direct relationship denotes a statistically significant relationship between a certain component and speechreading. An indirect relation denotes a relationship between two component variables, where one is indirectly related to speechreading via the other, which is in turn, directly related to speechreading.

In a similar way it is also possible to classify the effects of a certain component process into two categories. One is specific in the sense that it is tied to a certain speechreading condition (in the direct case), or tied to only one of the direct predictors (in the indirect case). The other is general, in the sense that skillful performance on the test taxing the component process is related to all kinds of speechreading conditions (in the direct case), or is responsible for facilitation of performance in more than one predictor variable (in the indirect case).

Given these two dimensions, it is possible to establish a taxonomy as to which kind of relationship (i.e., direct or indirect) and which kind of effect (general or specific) performance on a certain perceptual or cognitive component test is responsible for. Table 1 shows how the results from the present thesis may be classified according to this taxonomy. Note that when there is a significant relationship between a criterion and several predictor variables from the same component process, only the predictor variable with the strongest relation to the criterion is included in the taxonomy.
Table 1

**Taxonomy of Cognitive and Perceptual Components with Respect to their Type of Effect on and Type of Relation to Sentence-based speechreading. Numbers within Parentheses.**

Refer to the Empirical Studies in This Thesis.

<table>
<thead>
<tr>
<th>Type of Effect</th>
<th>Type of Relation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific</td>
<td>Direct</td>
<td>Indirect</td>
</tr>
<tr>
<td>Inference-making (3,4)</td>
<td>Context-free Inference-making (3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Semantic Decision Making Speed (4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Working Memory Capacity (3)</td>
</tr>
<tr>
<td>General</td>
<td>Information-processing Speed (4)</td>
<td>VEP (Amplitude) (1)</td>
</tr>
<tr>
<td>Word-decoding/discrimination (2,4)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As indicated by the taxonomy, three types of independent (cf. Study 4) component processes are directly associated with speechreading performance: Word-decoding/discrimination, information-processing speed and inference-making, whereas a number of others are related in an indirect fashion. The results from the present studies replicate the results by Gailey (1987) in the sense that the component processes word-decoding/discrimination and inference-making are related to speechreading performance. One extension to her results is that we can demonstrate that an information-processing speed component is involved and generally related to speechreading success. A second is that we can also show that a number of other component processes contribute indirectly to speechreading performance.
Moreover, with respect to the tentative model outlined previously in this thesis, the results give a possibility to revise and suggest specifications of certain components included in the model. That is, we can now describe how (i.e., directly or indirectly) certain components are related to speechreading, and to which kind of situations (general or specific) they relate; no such assumptions were made in the tentative model. Rather, the components included in the tentative model were assumed to be direct predictors of speechreading.

In the tentative model, it was hypothesized that it would be necessary to decode and discriminate as much visual information as possible from the spoken stimuli for further processing of the spoken message. The results suggest that both aspects of visual information-processing proved to be related generally and directly to speechreading performance, one of these (i.e., word-decoding) is more strongly related than the other (i.e., Study 2). Further related to this skill is one aspect of VEPs (i.e., the amplitude measure). A high amplitude is indirectly related to all kinds of speechreading situations (i.e., Study 1). Thus, support for the assumption outlined in the tentative model is gained by the results from the present studies, and, at a more specific level, there are indications as to how different aspects of this component vary in their ability to predict speechreading performance.

As indicated in the taxonomy, skilled inference-making is related to specific speechreading situations. In the present studies (i.e., Study 3), this is shown by the "less skilled" inference-makers' inferior performance in the speechreading condition where a relatively low level of contextual support was offered together with the speechreading task, and thus, requiring a larger number of inferences to be drawn (see also Lyxell & Rönberg, 1987a, b, for similar results). Further, the results also imply that, although both operationalizations of inference-making were related to speechreading, one proved to be a better predictor (i.e., sentence-completion) than the other. Thus, the results from the present studies give a possibility to specify the tentative model with respect to how skilled inference-
making is related to speechreading performance, as the results from this study suggest a relationship to certain specific speechreading conditions. And, similar to the visual information-processing component, tasks tapping particular features within the inference-making component vary in strength as to how they relate to speechreading performance.

Moreover, working memory capacity and an indice of long-term memory access (i.e., speed of semantic access) are also related to specific speechreading conditions (i.e., Study 3 and 4). However, the nature of this relationship is indirect, as both relate to speechreading via inference-making. Thus, as suggested in the tentative model, it is necessary to have resources to buffer up information in a temporary working memory until necessary information has been gathered to make an inference possible, and to rapidly access information from long-term memory. However, this applies only to specific speechreading situations. This indirect and specific relationship is indicated by all short-term memory tasks used, and by two out of four tests of long-term memory access tests.

Speed of information-processing is, as expected from the tentative model, related to speechreading (i.e., Study 4). This relationship is indexed by two information-processing speed parameters (i.e., by the level of asymptote and the test of lexical decision speed in this component). The implication of this is that the ability to rapidly process information may give the speechreader a possibility to allocate processing resources to other activities during speechreading. A slow information-processing ability might, on the other hand, become a "bottleneck" with serious consequences for speechreading, as this ability relates to all kinds of speechreading situations, relative to components associated with specific speechreading conditions. Thus, the specification of the tentative model is that some features of information-processing speed relate to speechreading in a direct and a general fashion, whereas other aspects of this speed relates to speechreading in an indirect and specific fashion.
In sum, the results from the present studies have made it possible to establish a taxonomy in which it is possible to specify the tentative model as to how certain cognitive component processes are related to speechreading, and for which kind of speechreading conditions they are most sensitive. Further, in some instances it is also possible to demonstrate that certain aspects within a given component may predict performance better than other aspects (cf. word-decoding/discrimination).

Moreover, as most of the work in the present thesis is descriptive in nature, further research is clearly needed in order to determine how a certain component influences speechreading. For example, in the direct case (according to the taxonomy), we have to gain more knowledge of a causal nature as to how and when inference-making influences the speechreading process. Similarly, in the indirect case, we need to know under what experimental conditions an individual's short-term memory capacity is critical to the inference-making process in speechreading. This type of experimental investigation can, and indeed, should be carried out for each component process in each of the cells included in the taxonomy. Further, we also have to test whether it is possible to falsify the ascribed role of a given component in the taxonomy. For example, under what conditions is it possible to classify skilled inference-making into another category?

A further implication of the taxonomy is that there is a hierarchical structure (i.e., direct or indirect relationships) among the components included. It is a task for further research to determine more precisely this hierarchical structure behind speechreading skill, using more powerful statistical tools than in the present series of studies (e.g., LISREL). However, this would require a more homogenous population than the one used here, also more theoretically well-established tests (predictor, as well as criterion tests), and a more precise knowledge as to how certain cognitive components influence each other in a causal sense.
The second objective of the present thesis was to investigate the processing parallels between speechreading and auditory speech perception. The results from Study 2 suggest that there are similarities in the initial phase of the word recognition process. However, it was also concluded that a theory of visual speech perception must deemphasize the importance of reliance on initial visual characteristics of a word, and thus allow for correction of absent (due to invisible phonemes) or misfed (due to perceptual similarity among e.g., syllables) information.

The third major result from the present set of studies is the absence of effects due to hearing-impairment. This is not a new finding. Previous research has demonstrated that hearing-impaired individuals are not better speechreaders than normal controls (Clouser, 1976, 1977; Conrad, 1977; Lyxell & Rönnberg, 1987b, in press a, 1989; Mogford, 1987; Rönnberg & Lyxell, 1986; Rönnberg, Öhngren, & Nilsson, 1982, 1983). The contribution from the present studies is that we can demonstrate this to be valid for molar as well as molecular levels of speechreading performance. A further contribution is that we can demonstrate that there is no difference in performance between hearing-impaired and controls in the component processes critical for speechreading, or how they relate to speechreading. The results from the present thesis concern groups of moderately hearing-impaired subjects. Therefore, the results should perhaps not be surprising, as individuals having this level of hearing loss possess some residual hearing capacity, and their hearing-impairment as such is not sufficient to trigger a shift of, for example, coding or information-processing strategies.

However, effects of hearing status on cognitive components are suggested by two studies from our own laboratory (Lyxell & Bäckman, 1989; Lyxell & Rönnberg, 1989a), wherein we could demonstrate that a group of subjects with an acquired deafness (i.e., a hearing-loss greater than 95 dB on the "better" ear) performed significantly inferior to a group of normal controls in a task requiring that the
subjects make decisions about word homophony (requiring use of an internal speech code). This difference was apparent only when decision accuracy was considered, not decision speed. There was also a relation between decision accuracy and speechreading performance. Moreover, Rönnberg, Öhngren, and Lyxell (1987) could demonstrate that a group of impaired subjects (also with an acquired deafness) abstracted information to a higher extent than normal hearing subjects on a text recognition task modelled after Bransford and Franks (1979). However, this abstraction was not related to speechreading performance. In sum, these results imply that there is no effect on cognitive capabilities, when the subjects have residual hearing capabilities (with or without hearing aids), whereas there may be some effect when no such residual hearing is available (i.e., acquired deafness). Such a conclusion must obviously be accepted with due caution, as there could be specific reasons why acquired deafness at adult age covaries with a performance decrease on any cognitive task.

Provided that there are no differences in speechreading performance or in component processes critical to the skill between hearing-impaired and controls, it may still be informative to investigate possible differences in speechreading between a group of hearing-impaired and normal hearing subjects. That is, even if there is no reported study that can demonstrate any superiority of one group relative to another, it is nevertheless, an often reported clinical observation that some hearing-impaired individuals develop extraordinary skills in speechreading. Another frequently reported clinical observation is that hearing-impaired individuals suffer from severe problems in speechreading. These "extreme" individuals are presumably "hidden" in a research design, where the purpose has been to make inferences about a particular group's performance, and where the intra-group variability has been seen as a nuisance variable (cf. a similar discussion for the visually impaired, Warren, 1982; see also Carroll, 1988). It is quite possible that this "error
variance" could indicate something of theoretical importance, for example, the use of different strategies.

In conclusion, the following main contributions have been made in the present thesis: (a) A taxonomy for components critical to speechreading skill has been advanced, and a model for the speechreading process has been suggested, (b) cognitive and perceptual similarities/differences between speechreading and speech perception has been proposed, and (c) the absence of compensatory patterns in speechreading, and for components critical to speechreading due to a moderate hearing-impairment has been repeatedly demonstrated.
References


the internal lexicon: Effects of systemacity and relative frequency of meanings.
Journal of Verbal Learning and Verbal Behavior, 10, 57 - 62.


Rönnberg, J. (1989). Decline of cognitive and communicative function: The effect of
chronological age and "handicap age". Submitted manuscript.

Hjelmquist and L-G Nilsson (Eds), Communication and handicap: Aspects of
psychological compensation and technical aids, (pp 19-38). Amsterdam:
North Holland.


evaluated by means of TV and real-life presentation: A comparison between a
normally hearing, moderately impaired, and profoundly hearing-impaired
group. Scandinavian Audiology, 12, 71 - 77.


potentials: Relation to adult speechreading and cognitive function. Journal of
Speech and Hearing Research.

aging. New York: Springer Verlag.

Psychology: General, 113, 345 - 371.

E. Birren, and K. W. Schaie (Eds.), Handbook of the psychology of aging (pp.


Summerfield, Q. (1987). Some preliminaries to a comprehensive account of audio-visual speech perception. In B. Dodd and R. Campbell (Eds.), Hearing by eye: The psychology of lipreading (pp. 3-51). London: Lawrence Erlbaum Ass.


Wong, W., & Taaffe, G. (1958). Relationship between selected aptitude and personality tests and lipreading ability. *John Tracy Clinic Research Papers VII*, Los Angeles, John Tracy Clinic.