Cognitive and communicative function: The effects of chronological age and “handicap age”
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Three classes of cognitive tests (short-term memory, long-term memory access/recall, and verbal ability) and one class of communicative tests (visual speech-reading) were administered to 49 hearing-impaired and 69 normal hearing subjects, varying in age between 23 and 75 years. It was found that when dB-loss and "handicap age" were partialled out, the negative effects of cognitive ageing remained: Speed in accessing alphanumeric symbols from long-term memory and as rehearsal speed correlated substantially with chronological age. Discriminant analyses revealed a communality between the discrimination of old from young subjects, and skilled from less skilled speech-readers: Visual decoding skill and rehearsal speed constituted the common discriminators. Departing from this result, an age-dependent componential model of visual speech-reading is delineated, with particular reference to the assumption that a temporally early lexical access system is crucial to the decoding of lip movements.

INTRODUCTION

The majority of adults who acquire their hearing impairment or deafness in adulthood are relatively old. The combination of old age and hearing impairment may be especially detrimental to their communicative abilities. Given the seriousness of this problem, the purpose of the present paper is to examine cognitive ageing from the perspective of one particular communicative function, i.e. speech-reading. Speech-reading is a general term conveying that not only decoding of lip movements (i.e. lipreading) is not alone sufficient for communication. Residual hearing as well as gestural and contextual infor-

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mation also constitute factors relevant to the definition of this form of communication (Rönnberg & Lyxell, 1986). In the present paper, visual – in contrast to audio-visual – speech-reading is examined.

The concept of cognitive and communicative compensation refers to the development of superior skills/strategies due to some type of impairment, compared to a matched control group. For the hearing-impaired, it seems reasonable to assume that both cognitive and communicative compensation should occur, as proficient speech-reading depends on certain inferential skills (Jeffers & Barley, 1971). The reason for this is that hearing-impaired individuals have to depend on visual speech-reading, particularly in noisy environments. This putative compensation should occur despite the use of hearing-aids, as modern aids fail to simulate the intricacies of selective attention (Plomp, 1986).

The hearing-impaired subjects examined in the present study were impaired to such an extent that they had to depend on visual speech-reading in their everyday communication. However, as revealed in a number of studies, compensation could not be observed, neither for cognitive nor for speech-reading abilities (Lyxell, 1989; Lyxell & Rönnberg, 1987a; 1989; in press a; Rönnberg, Öhngren, & Nilsson, 1982; 1983; see also studies cited in Mogford, 1987). The conclusion from this set of studies is that the impairment per se does not provoke any spontaneous compensation; rather, speech-reading skill appears to depend on certain characteristics of the individual's cognitive make-up (Lyxell, 1989).

COGNITIVE SKILLS IN SPEECH-READING

It is recognised that short-term memory capacity constitutes an important component in the cognitive architecture underlying visual speech-reading skill (e.g. De Filippo, 1982; Lyxell & Rönnberg, 1989; Sharp, 1972). The capacity to hold information in an active state supports the verbal inference-making processes (i.e. intelligent guesswork) necessary for speech-reading. That is, short-term memory indirectly supports speech-reading, whereas verbal inference-making constitutes a direct predictor of speech-reading skill (Lyxell & Rönnberg, 1987a; 1987b; 1989). Another skill that supports speech-reading is the ability to decode words from lip movements (Gailey, 1987; Lyxell & Rönnberg, in press a; in press b). Also, certain aspects of visual evoked potentials are related to word decoding (Rönnberg, Arlinger, Lyxell, & Kinnefors, 1989), suggesting that short-lived visuo-neural memory traces aid a visual analysis of lip movements (cf. Nättänen, 1986). Thus, the two basic cognitive components that directly affect visual speech-reading skill are visual word decoding and verbal inference-making (De Filippo, 1982; Gailey, 1987; see also Lyxell, 1989).
COGNITIVE AGEING AND SPEECH-READING

Most previous research on the relation between chronological age and speech-reading has examined deaf children. The age variable has mainly been regarded as an instrument to uncover practice effects (for a summary, see Jeffers & Barley, 1971). However, the magnitude of these correlations have not been high (Craig, 1964; Evans, 1960; 1965; Heider, 1947; Utley, 1945) and several covariates may have complicated the picture (e.g. verbal ability, general I.Q.). In subsequent research on older adults, the purpose has been to establish that visual speech perception is age-dependent (e.g. Ewertsen & Nielsen, 1971; Farrimond, 1959; Goetzinger, 1954; Pelson & Prather, 1974; Shoop & Binnie, 1979; Simmons, 1959). However, in this research the criterion variables have not been designed to pick up age-dependent cognitive changes.

From a cognitive ageing perspective different questions may be asked: Which, if any, cognitive abilities, affected by the ageing process, play an important role in visual speech-reading? Does an age-dependent componential model of speech-reading in some interesting sense show similarities with the age-independent model?

To refine and expand the componential structure behind visual speech-reading skill in general, and the age-dependent structure in particular, three classes of cognitive tests were used in the present study: short-term memory recall, long-term memory access/recall, and verbal ability. To explore and cover potentially important task features, a number of tests within each class were employed. The classes were chosen because (a) they tap cognitive functions known to be affected by the ageing process (Botwinick, 1978; Light & Anderson, 1985; Salthouse, 1985a), (b) they are relevant in the light of the cognitive components underlying speech-reading skill (Lyxell, 1989), and (c) they are also motivated on comparative grounds, as they play critical roles for listening comprehension (Cohen, 1987; Gordon-Salant, 1987), as well as for reading comprehension (e.g. Dixon & Bäckman, in press; Dixon, Hultsch, Simon, & von Eye, 1984; Hartley, 1986).

**METHOD**

**Organisation of Database**

A total of 118 subjects were tested, 49 of whom were hearing-impaired; the remaining 69 were normal hearing control subjects. All of the subjects participated in two test sessions. In session I, the following verbal and visual speech-reading tests were included: (a) sentence completion, (b) sentence-based speech-reading, (c) word completion, (d) word decoding, and (e) vocabulary. In session II, one class of long-term memory tests...
(including both access and recall tests) and one class of short-term memory tests were employed.

Subjects
A total of 49 hearing-impaired subjects (16 males and 33 females) participated. Their mean age was 50.4 years (S.D. = 11.0 years), and the average duration of impairment (i.e. “handicap age”) was 29.7 years (S.D. = 16.3 years). They had used their hearing-aids for an average of 15.1 years (S.D. = 12.8 years), and all subjects who used a hearing-aid wore it during the test sessions. Their better ear three-frequency average impairment (500, 1000, and 2000 Hz) was 66.2 dB, ISO 389 (range = 32–125 dB, S.D. = 23.6 dB), collected from their most recent medical records. All of the subjects had normal or corrected-to-normal vision. A total of 69 normal hearing subjects (21 males and 48 females) served as controls. Their mean age was 48.8 years, with an S.D. of 11.6 years. The subjects received the equivalent of £5 per session for their participation. All subjects were tested individually at the Department of Education and Psychology, University of Linköping. The cumulative age distribution of the database is shown in Fig. 1. It is important to note that the distribution is relatively rectangular across the age-span.

Session I
Note that somewhat dense descriptions of the tests used in both sessions I and II are offered. For more detailed descriptions, the reader should consult Rönnberg et al. (1989).

Sentence Completion Test. To assess the subjects’ context-bound, verbal inference-making ability (guessing), a sentence-completion test was administered. Here the subjects were presented with sentences, printed on separate cards, that had some (4–6) words missing. Twenty-four sentences were subdivided into three blocks, with each block consisting of eight sentences, referring to a specific contextual frame. Each subject first read the contextual frame (e.g. a restaurant scenario) from the top of the answer sheet, after which the experimenter exposed the incomplete sentence for 7 sec. The response interval was 25 sec per sentence. The proportion of words filled in appropriately (with syntactic and semantic appropriateness, and scenario restrictions considered), averaged over the 24 sentences, served as the measure of sentence completion skill.

Word Completion Test. To assess the subjects’ context-free, verbal inference-making ability, a word completion test was administered. The
Subjects were asked to complete 30 unrelated common Swedish nouns. Two to four letters were to be filled in for each word. Each incomplete noun was shown to the subject (on a separate sheet of paper) for 10 sec. Then the subjects had 10 sec to complete the word. The proportion of words correctly completed constituted the dependent measure.

Sentence-based Speech-reading Test. The same type of material was used for the speech-reading test as for the sentence completion test (with the same types of scenarios, but with different sentences). Four sentence lengths were used: 3-word, 6-word, 9-word, and 12-word sentences. A JVC VHS videotape recorder was used to present the material on a 66-cm Tandberg TV-monitor in the following way. First, the talker appeared and was "silent" for 3 sec, then all sentences were presented with the sound turned off. The viewing distance was 3 m, and the talker was visible from his shoulders up. The response interval was 25 sec. The subjects were instructed to write down, verbatim, the words that they had been able to speech-read; they were also encouraged to guess the rest of the message. The same scoring procedure was used as for the sentence completion test.

Word Decoding Test. Semantically unrelated Swedish words were used as test items. The presentation of both the first and the second word in the word-pair was unimodal (video only), the second word being presented after either a short (0.5 sec) or a long (5.0 sec) time interval. For each trial,
the subject’s task was to indicate whether the second word (i.e. the comparison word) was the same as the first (i.e. the test word). Each trial included four types of comparisons between the test word and a comparison word. One comparison word was the same as the test word (i.e. the target). A second comparison word was a lure that was phonologically similar for the first phoneme of the test word, whereas a third type of lure was similar for the last phoneme. The same equipment and talker as for the sentence-based speech-reading test were used. First, the talker appeared on the TV-screen and remained “silent” for 3 sec. Then, the test word was presented, the time interval (short or long) elapsed, and the comparison word was presented. The test word was re-presented before a new comparison word was presented, and so on, until the fourth pair of the trial had been presented. The response interval was 10 sec and the subject’s task was to indicate, by writing down a digit (1 to 4), which of the four comparison words was the same as the test word. This procedure was repeated for each of the 16 trials. The same presentation and recording procedures were used as in the sentence-based speech-reading test. The proportion of target words identified correctly constituted the dependent measure.

**Vocabulary Test.** A test of vocabulary comprising 70 items was administered. The subject’s task was to choose one of four alternatives that constituted an antonym to each target item. This test was a paper-and-pencil test, and 14 min were allowed for task completion. This type of test was chosen as it has proven to be a good predictor of verbal ability (Hunt, 1985). The proportion of items solved correctly constituted the dependent measure.

**Session II**

Both the long-term memory access/recall tests and the short-term memory tests were administered by a computer program: Text-Information-Processing-System (TIPS: Ausmeel, 1988). The order of test presentation is automatically randomised by TIPS, and thus unique for each subject.

**Long-term Memory Access Tests**

**Physical Matching.** The task was to match letter-pairs for physical identity (Posner & Mitchell, 1967). Out of 32 letter-pairs, 16 pairs were physically identical.

**Name Matching.** The task was to match the name of the letter, instead of its physical identity (Posner & Mitchell, 1967). Out of 64 pairs, 32 had the same name.
Lexical Access. The task was to decide whether a string of three letters constituted a true word or not. Out of 100 items, 50 were true words and 50 were nonwords. All true words were common, Swedish three-letter words.

Semantic Access. The task was to decide whether a word belonged to a certain predefined semantic category or not (Hogaboam & Pellegrino, 1978). Out of 96 items, 48 words belonged to the semantic categories and 48 words were unrelated.

For all long-term memory access tests, presentation characteristics were the same, and latency data were based on the average of each subject’s yes/no responses. Derived measures of reaction time (e.g. slopes or intercepts) were not used, as the average latency has been found to be an equally good predictor of cognitive ageing (Salthouse, 1985b).

Long-term Memory Recall Tests

Primacy. A traditional list-learning procedure was employed in which eight 12-item lists of unrelated words were presented at a rate of 1 sec per item. The response interval was 2 min. Primacy was computed as the proportion of words that were recalled from the first four words, averaged over the eight lists, thus constituting an index of long-term memory (Glanzer, 1972).

Asymptote. The asymptote was computed as the proportion of words recalled from the middle section (i.e. four positions) of the serial position curve. The asymptote is included under long-term memory recall, because it represents the bottleneck of information transfer (e.g. by means of rehearsal) to long-term memory (Salthouse, 1980; 1982).

Short-term Memory Tests

Digit Span. A series of digits was presented at a rate of one digit per 0.8 sec. After the subjects had attempted to recall the digit series orally in the correct serial order, the experimenter pushed a button and the next sequence of digits was presented, and so on. The first span size employed was three digits, the next was four, and so on, ending with a span of eight digits. The response interval was maximised to 2 min.

Word Span. The same procedure was used with words, the difference being that semantically unrelated and phonologically dissimilar words (see Baddeley, Thomson, & Buchanan, 1975) were presented.
**Reading Span.** The reading span test was a version of Baddeley, Logie, Nimmo-Smith, and Brereton’s (1985) test. The subjects read a sentence which was presented word-by-word at a rate of one item per 0.8 sec. The sentences varied from three to six words, and the subject’s task was to say out loud “yes” if the sentence made sense and “no” if it was absurd. Only 1.75 sec was allowed for the yes/no response before the next sentence appeared. The subject’s second task was to recall (after each sequence of sentences) the final word of each sentence in correct serial order. Sentence-span size varied from three to six. The same response interval as for the other span tests was employed.

All span tests had the same scoring criterion: The proportion of items each subject correctly recalled in correct serial order, averaged across all span sizes.

**Recency.** The previously mentioned list-learning procedure was employed, where recency was computed as the proportion of words recalled from the final four words, thus constituting an index of short-term memory (Glanzer, 1972; Rönnberg & Nilsson, 1987).

**RESULTS AND DISCUSSION**

The results are presented and discussed in three sections: (1) cognitive and communicative indices of ageing; (2) comparison between cognitive discriminants for ageing and cognitive discriminants for visual speech-reading; and (3) an age-dependent componential model of visual speech-reading.

**Cognitive and Communicative Indices of Ageing**

The overall means and standard deviations for all tasks collapsed across groups are shown in Table 1. For the memory span tests, we replicate the expected decrease in performance as a function of test complexity (Dane-man & Carpenter, 1980). An analysis of variance (ANOVA) showed a significant effect of type of span test \( F(2,168) = 468.30, P < 0.001 \). Subsequent \( t \)-tests indicated reliable differences among all three tests (all \( P < 0.01 \)). Secondly, as shown by performance on the recency, asymptote, and primacy portions of the serial position curve, the expected bow-shaped pattern (Murdock, 1962) was obtained \( F(2,166) = 129.31, P < 0.001 \). Again, \( t \)-tests indicated reliable differences among all three portions of the curve (all \( P < 0.01 \)). Thirdly, the main effect of type of long-term memory access tests was also significant \( F(3,243) = 39.34, P < 0.001 \). Physical matching was faster than name matching \( P < 0.01 \), hence replicating previous data (Posner & Mitchell, 1967; Posner, Boies, Eichelman, &
TABLE 1

<table>
<thead>
<tr>
<th>Short-term Memory Recall</th>
<th>Long-term Memory</th>
<th>Verbal Tests</th>
<th>Visual Speech-reading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>S.D.</td>
<td>n</td>
</tr>
<tr>
<td><strong>Access</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit span</td>
<td>0.75</td>
<td>0.11</td>
<td>85</td>
</tr>
<tr>
<td>Word span</td>
<td>0.49</td>
<td>0.09</td>
<td>85</td>
</tr>
<tr>
<td>Reading span</td>
<td>0.40</td>
<td>0.14</td>
<td>85</td>
</tr>
<tr>
<td>Recency</td>
<td>0.45</td>
<td>0.14</td>
<td>84</td>
</tr>
<tr>
<td><strong>Recall</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primacy</td>
<td>0.34</td>
<td>0.12</td>
<td>84</td>
</tr>
<tr>
<td>Asymptote</td>
<td>0.17</td>
<td>0.08</td>
<td>84</td>
</tr>
</tbody>
</table>
Taylor, 1969). The lexical access times correspond well with previously reported estimates (Hunt, 1985, p. 41). The semantic access data replicate Hunt, Davidson, and Lansman's (1981) data in that semantic categorisation was faster than the name matching of words ($P < 0.01$).

Pearson correlations between overall scores on each test in sessions I and II and the chronological age of the subjects are displayed in Tables 2 and 3. Two levels of analysis were used: the overall level of correlations across groups (Table 2), and the correlations specific to the hearing-impaired subjects (Table 3). The latter correlations were also evaluated with handicap age and dB loss partialled out (Table 3).

As can be seen in Table 2, the single-most age-sensitive class of tasks are the long-term memory access tasks. The physical matching test seems to be the most age-sensitive ($r = 0.43$, $P < 0.001$) compared to the relatively more complex decisions demanded for lexical and semantic items. Salthouse (1985b) concluded in a review that the median correlations for simple reaction time and choice reaction time were 0.28 and 0.43, respectively. Thus, the present data do not deviate from previously reported results. Note also that the trade-off between speed and accuracy was unproblematic, as the average error rates were very low: 3.7, 6.0, 8.2, and 3.1% for the physical matching, name matching, lexical access, and semantic access tests, respectively. Partialling out for error rate had only a minor effect on the correlations.

For long-term memory recall, the asymptote level seems sensitive to cognitive ageing. According to Salthouse (1980), the asymptote represents a cognitive speed function, i.e. the amount of time needed per rehearsal. Thus, both the asymptote level and latency data, drawing on long-term memory, may converge on a basic speed function (Salthouse, 1985a).

For the visual speech-reading tasks (see Table 2), the sentence-based speech-reading test was more strongly correlated with age than word decoding. As short-term memory capacity and verbal inference-making skill both represent important predictors of sentence-based speech-reading skill (Lxell & Rönnberg, 1987a; 1987b; 1989; Sanders & Coscarelli, 1970; Williams, 1982), age-related deficits could thus be expected (Light & Anderson, 1985; Taub, 1979). An inspection of the data in Table 2 does not, however, lend support to this suggestion: Age is only moderately correlated with the short-term memory tests and the verbal tests. The proposal is therefore that inherent cognitive speed is needed for disambiguating and inferring the meaning from the relatively poor information conveyed by lip movements.

For the hearing-impaired (see Table 3), the overall pattern of data remains. What can be added is that the moderate correlations found for the short-term memory tests and the verbal tests at the overall level disappear. Hence, the picture becomes more distinct, i.e. the predominance
<table>
<thead>
<tr>
<th>Short-term Memory Recall</th>
<th>Long-term Memory</th>
<th>Verbal Tests</th>
<th>Visual Speech-reading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Access</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit span</td>
<td>-0.01</td>
<td>Physical matching 0.43***</td>
<td>Sentence completion -0.20*</td>
</tr>
<tr>
<td>Word span</td>
<td>-0.05</td>
<td>Name matching 0.31**</td>
<td>Word completion -0.10</td>
</tr>
<tr>
<td>Reading span</td>
<td>-0.26**</td>
<td>Lexical access 0.25**</td>
<td>Vocabulary -0.17</td>
</tr>
<tr>
<td>Recency</td>
<td>-0.27**</td>
<td>Semantic access 0.35***</td>
<td></td>
</tr>
<tr>
<td><strong>Recall</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primacy</td>
<td>-0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asymptote</td>
<td>-0.35***</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*P < 0.05; **P < 0.01; ***P < 0.001.
TABLE 3
Correlations for the Hearing-impaired Among the Short-term Memory Recall, Long-term Memory Access/Recall, Verbal, and Visual Speech-reading Tests with Chronological Age

<table>
<thead>
<tr>
<th>Access</th>
<th>Short-term Memory Recall</th>
<th>Long-term Memory</th>
<th>Verbal Tests</th>
<th>Visual Speech-reading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- dB Years</td>
<td>- dB Years</td>
<td>- dB Years</td>
<td>- dB Years</td>
</tr>
<tr>
<td>Digit span</td>
<td>0.01</td>
<td>0.06</td>
<td>0.00</td>
<td>Physical matching</td>
</tr>
<tr>
<td>Word span</td>
<td>-0.03</td>
<td>-0.03</td>
<td>-0.03</td>
<td>Name matching</td>
</tr>
<tr>
<td>Reading span</td>
<td>-0.15</td>
<td>-0.13</td>
<td>-0.18</td>
<td>Lexical access</td>
</tr>
<tr>
<td>Recency</td>
<td>-0.24</td>
<td>-0.35*</td>
<td>-0.21</td>
<td>Semantic access</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recall</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Primacy</td>
<td>-0.11</td>
<td>-0.03</td>
<td>-0.10</td>
<td></td>
</tr>
<tr>
<td>Asymptote</td>
<td>-0.43**</td>
<td>-0.44**</td>
<td>-0.43**</td>
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<td></td>
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</tr>
</tbody>
</table>

*The two right-most columns show correlations with age, partialled out for dB loss and number of years as handicapped (i.e. handicap age).

*P < 0.05; **P < 0.01; ***P < 0.001.
of speed-related measures. The communality in the overall pattern for the hearing-impaired and the total sample is further support for the previously reported lack of compensatory changes due to hearing impairment (e.g. Lyxell & Rönnberg, 1987a; 1989). Neither the potential effect of dB loss, nor handicap age (see the two right-most columns in Table 3), alter the basic pattern in any tangible fashion. Thus, chronological age constitutes a powerful index of the decline in cognitive function and visual speech-reading, whereas handicap age or dB loss are relatively unimportant.

The effects of cognitive ageing were also evaluated by means of one-way ANOVAs, for each test in the battery, with subjects divided into three age groups (young: mean age = 37.2 years, S.D. = 5.8 years; intermediate: mean age = 49.4 years, S.D. = 2.9 years; old: mean age = 62.1 years, S.D. = 5.8 years). As can be seen in Table 4, basically the same pattern as that from the correlational analysis is evident. But there are some deviations that make the picture even more clear. Cognitive ageing does not have any effect on short-term memory indices, or on the verbal tests. Although our subjects performed a dual-requesiment reading span task, age did not provoke decrements similar to previous reading span data (Gick, Craik, & Morris, 1988; Morris, Gick, & Craik, 1988). However, it may well be that the task was not sufficiently taxing: First, absurdity judgements of five-word sentences do not demand as much processing resources as true/false judgements; absurdity should be relatively easy to detect given the nature of our examples (e.g. “the policeman ate the cat”). Secondly, although word span and reading span performance were statistically different, the putative complexity effect is relatively small compared to the difference between word span and digit span. Thus, the dual task requirements resemble those of Light and Anderson (1985) and Hartley (1986), who found small differences between sentence span and word span, with a negligible age effect. The non-significant differences for the verbal tests agree with previously reported data (e.g. Burke & Harrold, 1988; Hultsch, Masson, & Small, in press; Perlmutter, 1986).

Finally, when the corresponding ANOVAs were computed for the visual speech-reading tests, only the main effect of age on the sentence-based test remained significant \(F(2,113) = 5.5, P < 0.005\). No interactions qualified the results (Lyxell & Rönnberg, in press b). Thus, visual speech-reading tasks are sensitive to age when they are context-bound, but increasing age only exerts a general detrimental, non-interactive effect on this type of task.

The results from this section can be summarised in four main points. First, handicap-specific factors do not induce any selective cognitive or communicative compensatory pattern. Second, speed of accessing over-learned information from long-term memory is dependent on the age of
## TABLE 4
Mean Performance, Standard Deviation, and Number of Cases for Each Age Group on the Tests Evaluated by One-way ANOVAs

<table>
<thead>
<tr>
<th>Class of Tests</th>
<th>Age Group</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Young</td>
<td>Intermediate</td>
<td>Old</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>S.D.</td>
<td>n</td>
<td>M</td>
<td>S.D.</td>
<td>n</td>
</tr>
<tr>
<td>Short-term memory</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit span</td>
<td>0.76</td>
<td>0.09</td>
<td>26</td>
<td>0.73</td>
<td>0.13</td>
<td>30</td>
</tr>
<tr>
<td>Word span</td>
<td>0.49</td>
<td>0.07</td>
<td>26</td>
<td>0.49</td>
<td>0.11</td>
<td>30</td>
</tr>
<tr>
<td>Reading span</td>
<td>0.45</td>
<td>0.11</td>
<td>26</td>
<td>0.38</td>
<td>0.14</td>
<td>30</td>
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<tr>
<td>Recency</td>
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<td>0.14</td>
<td>26</td>
<td>0.48</td>
<td>0.15</td>
<td>29</td>
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<tr>
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<tr>
<td>Physical matching</td>
<td>0.72</td>
<td>0.10</td>
<td>26</td>
<td>0.82</td>
<td>0.19</td>
<td>28</td>
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<td>Name matching</td>
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<td>0.16</td>
<td>26</td>
<td>0.89</td>
<td>0.19</td>
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<td>Lexical access</td>
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<td>0.13</td>
<td>26</td>
<td>0.88</td>
<td>0.18</td>
<td>29</td>
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<td>Semantic access</td>
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<td>0.74</td>
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<td>0.36</td>
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<td>29</td>
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<tr>
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<td>0.08</td>
<td>26</td>
<td>0.16</td>
<td>0.08</td>
<td>29</td>
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<tr>
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<td>Sentence completion</td>
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<td>39</td>
<td>0.60</td>
<td>0.17</td>
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<tr>
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<td>0.17</td>
<td>39</td>
<td>0.56</td>
<td>0.14</td>
<td>40</td>
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<tr>
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<td>0.17</td>
<td>36</td>
<td>0.72</td>
<td>0.17</td>
<td>37</td>
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Significance

- N.S.
- \( P < 0.01 \)
- \( P < 0.05 \)
- \( P < 0.001 \)
the subject; in particular the access of alphanumeric information. Third, rehearsal operation speed, as operationalised by the asymptote, constitutes yet another aspect of cognitive speed that is sensitive to age. Finally, the sentence-based speech-reading test was more dependent on age than the word decoding test.

Comparison Between Cognitive Discriminants for Ageing and Cognitive Discriminants for Visual Speech-reading

To discriminate old from young subjects, a two-group discriminant analysis was performed on the basis of two-thirds of the subjects. The intermediate third (the group ranging between 54 and 44 years, i.e. the same cut-off ages as for the ANOVAs) was excluded to optimise the age differences within the chosen range. The variables chosen for the discriminant analysis were those that had displayed a significant simple correlation with age in the overall analysis and that were the best predictors of a particular class (or subclass) of predictors (i.e. recency, physical matching, the asymptote, sentence completion, and word decoding). Three discriminants were significant: physical matching, word decoding, and the asymptote measure, in that order of relative strength (see Table 5). In other words, as compared to the young, older subjects can best be described as having slower retrieval speeds of overlearned symbols, as possessing a lower capacity of visual decoding of words, and as demonstrating slower rehearsal processes (Salthouse, 1980). There is a fair amount of accuracy in the prediction, as 78% of the cases were correctly classified. The corresponding discriminant analysis was computed for skilled vs less skilled speech-readers in the sentence-based speech-reading task. It can be seen in Table 6 that the asymptote, word decoding, recency, and sentence completion – in that order of relative strength – constituted the significant discriminants of

<table>
<thead>
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<th>Variables</th>
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<th>Wilk's Lambda</th>
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<tbody>
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<td>Physical matching</td>
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<td>Word decoding</td>
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<td>Asymptote</td>
<td>3.11</td>
<td>0.72</td>
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</table>

*Note: n = 26 in the young group and n = 27 in the old group.
TABLE 6
Variables that Discriminate Between Skilled and Less Skilled Speech-readers*

<table>
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<tr>
<th>Variables</th>
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<th>Wilk's Lambda</th>
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<tr>
<td>Asymptote</td>
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<tr>
<td>Word decoding</td>
<td>3.17</td>
<td>0.78</td>
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<tr>
<td>Recency</td>
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<td>0.78</td>
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<tr>
<td>Sentence completion</td>
<td>1.64</td>
<td>0.76</td>
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</table>

*Note: n = 30 in the less skilled group and n = 25 in the skilled group.

speech-reading skill. There is also a fair amount of accuracy in this analysis, in that 75% of the cases were correctly classified.

In sum, the two discriminant analyses revealed a communality, in that both involved the word decoding test and the asymptote measure. The interpretation of this result is that young speech-readers are at an advantage when decoding what there is to extract from lip movements, and in the speed with which the decoded elements may be rehearsed.

An Age-dependent Componential Model of Visual Speech-reading

According to the previous data concerning cognitive skills in visual speech-reading (Lyxell, 1989), only one of those two direct predictors, decoding, is directly dependent on age, whereas verbal inference-making is not. The present data show, that in addition to decoding, there is a direct age-dependence on a third predictor: the level of the asymptote. As both predictors exert direct (as opposed to indirect) effects on speech-reading, and are more powerful than inference-making, it is suggested that the age-deficit is localised to the key skills in speech-reading. This sets the stage for a straightforward age-dependent componential model of visual speech-reading.

The Asymptote. The intercorrelations between the asymptote and the class of verbal tests show low to moderate correlations (all r in the range of 0.15–0.25), whereas a systematic pattern can be observed for the span tasks, suggesting an increasing correlation with the asymptote as the complexity of the span task increases: r = 0.19, 0.36, and 0.45 for the digit, word, and reading span tasks, respectively (all P < 0.05). This implies that all span tasks draw on an active rehearsal component to maintain the items in their serial order (Hitch, 1985). This capacity becomes increasingly
important with dual-task requirements (Daneman & Carpenter, 1980). Also, the asymptote correlates systematically with all the speed indices ($r$ between $-0.22$ and $-0.29$, all $P < 0.02$). First, this result validates Salthouse's (1980) assumption that the asymptote might draw on a speed factor. Second, all speed indices are equally correlated with the asymptote, adding to the generality of the factor. Third, the speed indices are all highly intercorrelated (all $r$ between 0.48 and 0.67, all $P < 0.01$), again suggesting a certain amount of generality for the cognitive speed hypothesis to account for age-related changes in cognitive function (Salthouse, 1985b).

The general interpretation is that rehearsal needs to be fast, keeping the serial order of processed items intact. Equally important is that rehearsal operates independently of whether a single phoneme is processed, or whether processing concerns a lexical or a semantic unit. This latter task demand is especially prominent in speech-reading relative to other communication forms (e.g., reading), as there is no second chance once the utterance has been made. Maintained order of information at a high speed ensures that the reliance on context-bound inference-making is reduced. Thus, the present results indicate that the older speech-reader has a deficit in this rehearsal capacity.

**Decoding.** One of many obvious differences between normal listening and visually based speech-reading is that speech-reading is much harder because relatively few phonemes can be unambiguously recognised (Summerfield, 1987). One cognitive consequence of this state of affairs is that the speech-reader has to be fast in the "chase for meaning" of an utterance. The intercorrelations between the decoding test and the short-term memory or long-term access classes reveal no systematic pattern, but decoding correlates with the sentence and word completion tests in the verbal class ($r = 0.23$ and 0.28, respectively; all $P < 0.01$). This suggests that a perception-of-meaning strategy draws to some extent on verbal inferences. However, a prerequisite for such a strategy is that some aspect of cognitive speed is related to lexical access. Rönnberg (1987) found that decoding is very ($r$ around 0.60) dependent on lexical access by means of a phonological access route (see also Conrad, 1979). Thus, there is a speed factor involved, but in a more specific sense than for the asymptote. Yet another aspect of cognitive speed and lexical access was demonstrated by Lyxell and Rönnberg (in press a), who found (in a word decoding task) that speech-readers rely heavily on the initial phoneme of to-be-decoded words. The results suggest that the speech perception system is triggered by a mechanism that optimises lexical access early and rapidly (e.g. the initial cohort activation: Marslen-Wilson, 1987; see also Summerfield, 1983).
The general interpretation of such a temporally early lexical system is that it is relatively independent of contextual support (Lyxell & Rönberg, in press a). The fact that verbal inference-making (i.e. contextually embedded sentence completion) is not as important to speech-reading skill as decoding (Lyxell, 1989), may also explain why the need for assemblage and rehearsal of contextual elements in a capacious working memory is lessened. Thus, the present results suggest that the older speech-reader has a less efficient perception-of-meaning strategy due to less efficient lexical access.

In sum, age-dependent components represent simple, low-level functions (i.e. physical matching, word decoding, and the asymptote), whereas the age-independent predictions of speech-reading skill also encompass higher-order components (e.g. inference-making). The age-dependent model of visual speech-reading rests on the apparent communality on low-level, bottom-up cognitive functions.

CONCLUSION

An age-dependent model of visual speech-reading has to take the following into account: Handicap-related factors can be dismissed in the sense that they do not confound the effects of chronological age. Given this, the argument is that a temporally early lexical access system is crucial to decoding of lip movements. A high rate of rehearsal operations, drawing on long-term memory access speed, also serves the function of decontextualising the task. Again, the demand on the cognitive system is focused on efficient lexical access. It is precisely in these two respects that chronological age exerts its largest influence. These facts are at least suggestive of a basic cognitive speed function (Salthouse, 1985b).

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REFERENCES


