Language Comprehension in Older Listeners

Compréhension du langage chez les personnes âgées

by • par

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ABSTRACT

Many older adults experience more difficulty than younger adults when trying to comprehend language spoken in non-ideal conditions; this is often the case even for seniors who hear well in ideal listening conditions and are not candidates for hearing aids because they have little or no audiometric threshold elevation (for reviews, see Bergman, 1980; Willott, 1991). Since the publication of the report on "Speech Understanding and Aging" by a Working Group of the Committee on Hearing, Bioacoustics and Biomechanics (Committee on Hearing, Bioacoustics, and Biomechanics, 1988), several groups of hearing scientists and audiologists have established research programs dedicated to the investigation of how age-related changes in audition and cognition might interact during the comprehension of spoken language. In the present paper, the progress of these research groups is reviewed. The model and assumptions employed by hearing scientists and audiologists are compared to alternative models and assumptions that have been put forth by researchers in other disciplines who are also interested in how older listeners comprehend language. These disciplines include linguistics, cognitive psychology, social psychology, and sociolinguistics. Some of these alternative models have been described in the companion Special Issue of *JSLPA* on "Discourse and Aging" edited by Orange and Purves (1996b). The argument is made here that audiologists, especially those practicing rehabilitative audiology, need to reconcile a variety of models in order to gain a more integrated and holistic appreciation of how both stability and change in multiple domains influence the communication function of hard-of-hearing seniors.

ABRÉGÉ

Nombre d'adultes âgés ont plus de mal que les jeunes adultes à comprendre les paroles prononcées dans des conditions qui ne sont pas favorables. C'est souvent le cas même chez les aînés qui entendent bien dans une situation d'écoute idéale et qui ne tireraient aucun profit de l'amplification parce que leurs seuils audiométriques se rapprochent des normales (pour des études, voir Bergman, 1980; Willott, 1991). Depuis la publication du rapport sur «le vieillissement et la compréhension de la parole» (Speech Understanding and Aging) par un groupe de travail du comité sur l'audition, la bioacoustique et la biomécanique (Committee on Hearing, Bioacoustics and Biomechanics) (CHABA, 1988), plusieurs groupes de spécialistes en sciences de l'audition et d'audiologistes ont lancé des projets de recherche pour étudier comment les modifications de l'audition et de la discrimination, qui sont dues au vieillissement, interagissent dans la compréhension de la parole. L'auteur passe en revue les travaux de ces groupes. Le modèle et les hypothèses utilisés par les spécialistes en sciences de l'audition et les audiologistes sont comparés à d'autres qui ont été avancés par des chercheurs de différentes disciplines qui s'intéressent aussi à la manière dont les personnes âgées comprennent le langage. Entre autres disciplines, il y a la linguistique, la psychologie cognitive, la psychologie sociale et la sociolinguistique. Certains de ces autres modèles ont été décrits dans l'édition spéciale de la *ROA* sur «Le discours et le vieillissement», sous la direction de Orange et Purves (1996b). Selon l'auteur, les audiologistes, surtout ceux qui pratiquent en réadaptation, ont besoin de concilier divers modèles afin d'arriver à une appréciation mieux intégrée et holistique de la façon dont la stabilité et le changement dans de multiples domaines influent sur la faculté de communiquer des aînés malentendants.

KEY WORDS

audiologic rehabilitation • language comprehension • hard-of-hearing adults

Rehabilitative audiologists frequently hear older adults make comments like the following: "I hear, but I have trouble understanding", "sounds seem all jumbled up", "it is difficult to tell where sounds are coming from", "I understand when it is quiet, but I have trouble when it is noisy", "I understand when I'm talking to one person, but I have trouble in a group", "in a group, if I know who is talking then I can follow the conversation, but I have trouble when someone else starts talking", "when someone else starts talking sometimes I have to look around to see who it is", "if I know the topic of conversation then I do pretty well, but I often get lost when the topic changes", "people seem to talk too fast; I need more time to make sense of what has been said", "it is not so much that I can't understand what is said but that it is tiring to listen", "I sometimes pretend to understand because it isn't worth it to ask the talker to repeat because I'm afraid that it would be an imposition and it could annoy or make the talker impatient", "I don't know for sure when I hear correctly and when I don't", "it's hard to get jokes; you have to get the punchline right away or it isn't funny", "when I'm with two or more people, they start talking to each other and leave me out", "I don't enjoy social events any more". These comments have been made by many older adults, including those who wear hearing aids and those who do not because their pure-tone thresholds are near normal.

The comments of older adults leave us with the strong impression that their problems are more than simply a matter of not hearing low-intensity, high-frequency sounds. In particular, such comments reflect the important fact that these listeners *do* hear sounds. Nevertheless, especially in informationally complex, real-world conditions, they have difficulty deriving meaning from sound, sometimes with associated difficulties in segregating the distinct identities and the distinct spatial locations of multiple co-existing auditory objects (for an explanation of the concept of an auditory object see Bregman, 1990). These listeners are slow, uncertain, and sometimes unsuccessful in deriving meaning from sound. What meaning is derived may also be short-lived in memory. Perhaps worst of all, struggling to derive meaning may not only be mentally tiring for the listener, but it may even jeopardize social relations because the problems of the listener are, in turn, stressful for, confusing to, and often misinterpreted by communication partners.

Many researchers have concluded that the hearing-related communication problems of the elderly are not fully explained by elevations in audiometric pure-tone thresholds. First, hearing sensitivity is a poor index of impairment[1] (physical change) because there can be substantial histopathological change in the auditory periphery without corresponding elevation of pure-tone thresholds (for reviews, see Schneider, 1997; Willott, 1991, 1996). For example, Bredberg (1968) found a 40% loss of outer hair cells in the apex of the cochlea with only a 15 dB elevation in thresholds for low-frequency tones and a 25% loss of outer hair cells in the base of the cochlea with only a 20 dB elevation in thresholds for high-frequency tones. Clearly, the audiogram is a limited index of impairment and much physical damage may occur before audiometric change is evident.

Second, hearing sensitivity is also a poor index of disability[1] (change in performance or behavioural ability) because declines in auditory processing (Schneider, 1997), speech processing (Cheesman, 1997), language processing (Kemper, 1992), and comprehension (Wingfield, 1996) are observed even in older adults with clinically normal or near-normal audiograms. For example, audiometric thresholds cannot predict declines in monaural auditory temporal processing (Fitzgibbons & Gordon-Salant, 1996; Schneider, 1997) or binaural processing (Grose, 1996; Schneider, 1997). The physiological bases for these declines, and the relationships between disabilities and sub-clinical impairments await further investigation (Schneider, 1997; Willott, 1991, 1996).

Third, handicap[1] (change in ability to function in social roles) is poorly correlated with audiometric measures of hearing sensitivity (Erdman, 1994), and the correlation is even poorer for older adults than for younger adults (Lutman, 1991). The degree of handicap experienced by older adults may be modulated by many factors (Nespoulous, 1996; Pichora-Fuller, 1994). Such factors would include the specific nature of the person's hearing-related impairments and disabilities (for a discussion of the relationship between self-reported handicap and central auditory deficits, see Chmiel & Jerger, 1996; Jerger, Oliver & Pirozzolo, 1990; Stach, Loiselle, & Jerger, 1991), other impairments and disabilities such as deficits in vision or cognition (Ivy, MacLeod, Petit, & Markus, 1992), the physical environment (Hodgson, 1994), or the social environment, either at the interpersonal level (e.g., Ryan, Giles, Bartolucci, & Henwood, 1986) or the cultural level (McKellin, 1994). These non-auditory factors are likely to be even more varied for older adults than for younger adults. Therefore, notwithstanding the high-frequency sensorineural hearing loss typical of presbycusis and how it contributes to real-world hearing problems, to understand why older adults make the kinds of comments they do about their everyday listening[2] experiences, audiologists must look beyond the audiogram and appreciate the diversity of possible factors contributing to handicap within a more comprehensive theoretical framework.

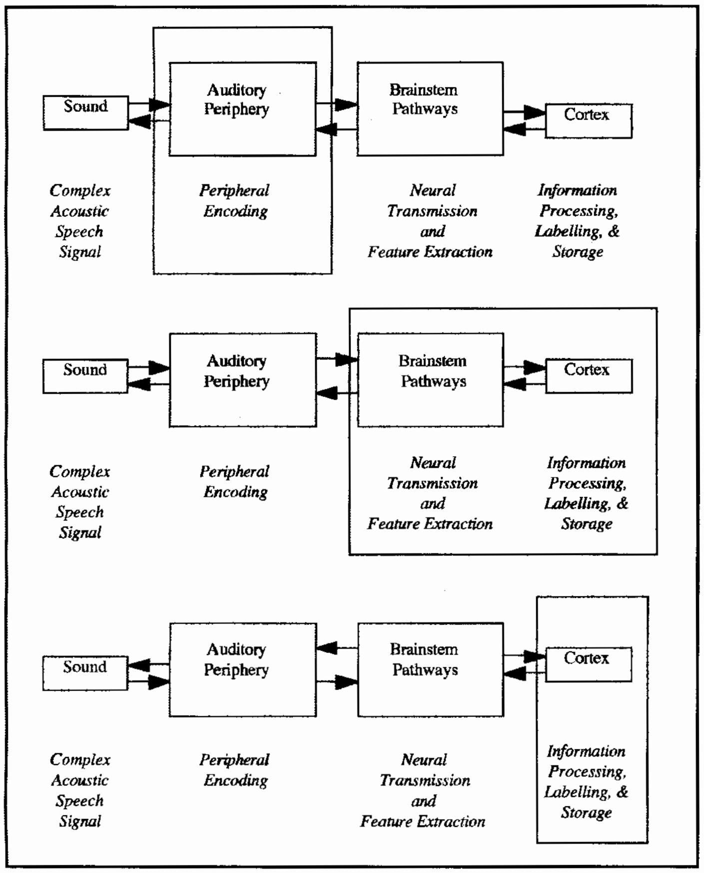
Models

The range of factors reflected in older adults' comments about their everyday listening experiences are not captured in any current model. In the present paper, five types of models from different disciplines are reviewed. The models are largely complementary; some are more generic and offer unifying concepts. Specifically, the following models will be discussed: (a) an auditory system model (Humes, 1996); (b) a cognitive information processing model of language comprehension (Kwong See & Ryan, 1996); (c) a psycholinguistic model in which language processing is autonomous from other cognitive processing except in non-ideal conditions (Kemper & Anagnopoulos, 1993); (d) a psychosocial/sociolinguistic interpersonal interaction model of communication predicaments (Ryan et al., 1986); and, (e) a non-autonomous language processing model based on working memory (Carpenter, Miyake, & Just, 1995). The first model elaborates on aspects of auditory processing, while the others simply assume that there is auditory input to subsequent linguistic, cognitive, and social information processing. The first model will be described and then the other models and related findings will be contrasted with it. Finally, an attempt will be made to reconcile the models and relate them to the practice of rehabilitative audiology.

Auditory System Model

Humes (1996) uses a highly schematic overview of the auditory system from periphery to cortex to contrast three hypotheses set forth in the CHABA (1988) report as possible accounts for age-related changes in speech understanding[3]: (a) the peripheral hypothesis, (b) the central-auditory hypothesis, and (c) the cognitive hypothesis (see Figure 1). Humes equates the peripheral hypothesis with cochlear function, the central-auditory hypothesis with brainstem function and modality-specific cortical function, and the cognitive hypothesis with non-modality-specific cortical function. He designates psychological processes corresponding to the three sites, respectively: (a) peripheral encoding, (b) neural transmission and feature extraction, and (c) information processing, labeling, and storage. The model depicts interaction, presumably through afferent and efferent pathways. The hypotheses differ, therefore, in terms of the primary site of age-related damage in the auditory system that is implicated.

Figure 1. Auditory system model as depicted by Humes (1996).



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The biophysical systems view depicted by Humes (1996) extends the approach of Schuknecht (1964, 1974) who argued for four sub-classes of presbycusis (sensory, neural, cochlear conductive or mechanical, and strial) based on specific sites of damage in the auditory periphery and thought to correspond to characteristic patterns of audiometric pure-tone thresholds and speech scores. Examining these four sub-classes of presbycusis plus two additional sub-classes (sensorineural and vascular), Willott (1991) concluded that there is good histopathological evidence for at least four of the hypothesized sub-classes: sensory presbycusis involving loss of outer hair cells, neural presbycusis involving loss of VIIIth nerve ganglion cells, sensorineural presbycusis involving a combination of sensory and neural factors, and strial presbycusis involving deterioration of the stria vascularis. Despite the histopathological evidence for distinct sub-classes of presbycusis, however, Willott (1991) argued that it is not possible to differentiate between these using clinical audiometry. An implicit assumption in such biophysical models is that distinct physical changes (impairments) are highly correlated to particular behavioural measures (disabilities). However, even considering only the auditory periphery, differential diagnosis is difficult because there is a lack of clear correspondence between specific types of physical change and specific behavioural results.

Over the last decade, there have been several attempts to use an auditory systems approach to determine how age-related changes in audition and cognition may account for the comprehension difficulties of older listeners. Humes and van Rooij and their colleagues emphasized the role of peripheral factors, while Jerger and his colleagues emphasized the role of central-auditory factors. These research groups administered batteries of auditory processing measures (usually monaural measures of peripheral function), batteries of cognitive measures, and batteries of speech perception or word recognition (called speech understanding)[3] measures, and then performed correlational analyses to determine which auditory and/or cognitive measures accounted significantly for variance in the measures of speech perception and/or word recognition. A significant contribution of peripheral auditory measures in accounting for variance in measures of speech perception or word recognition would be taken as evidence that age-related changes in the auditory periphery are implicated. Likewise, a significant contribution of cognitive measures, especially with corresponding cognitive profiles on tests presented in both auditory and visual modalities, would be taken as evidence that age-related changes in the cortex are implicated. A significant contribution of central auditory measures would be taken as evidence that age-related changes in the brainstem are implicated. The findings of these research groups will be summarized. Only the major findings, conclusions and points not stressed in the recent review by Humes (1996) will be highlighted here.

Humes' group initially evaluated the simplest peripheral hypothesis: that the degree of pure-tone hearing loss is the primary factor underlying speech perception or word recognition difficulties in the elderly. Three groups were usually compared: presbycusics, young adults with normal hearing, and young adults with simulated hearing loss. The simulated hearing losses were shaped using masking to match the sensorineural hearing losses of the presbycusics with respect to pure-tone threshold elevation, and the researchers assumed that loudness recruitment and level-specific changes in frequency resolution were also mimicked (Humes, 1996; Humes, Espinoza-Varas, & Watson, 1988; Humes & Jesteadt, 1991). Presbycusics and young listeners with simulated hearing loss performed equivalently on monaural identification of closed-set nonsense syllables in conditions of reverberation, background noise, and both reverberation and background noise (Humes & Roberts, 1990) and when the nonsense syllables were degraded spectrally using bandpass filtering from 500 to 2000 Hz, and temporally using a reverberation time of .8 seconds (Humes & Christopherson, 1991). Young-old listeners (63-74 years old) performed better on the syllable identification test than old-old listeners (75-83 years old) when cognitive status was not controlled, suggesting that there might be age-related differences within the old group; however, these differences between young-old and old-old listeners were eliminated when audiometric and cognitive status (IQ and digit-span memory) were matched (Lee & Humes, 1992). In a later study of 50 presbycusics (Humes, Watson, Christensen, Cokely, Halling & Lee, 1994), the battery of measures was expanded to include: the Test of Auditory Capabilities (TBAC; Christopherson & Humes, 1992; Watson, Johnson, Lehman, Kelly, & Jensen, 1982); standard clinical measures of cognitive function (WAIS-R, Wechsler, 1981; WMS-R, Wechsler, 1987); and a larger battery of speech tests, including open-set recognition of sentence-final words. All speech measures were highly inter-correlated, and the degree of sensorineural hearing loss (pure-tone average of thresholds at 1, 2, and 4 kHz) was the primary factor associated with speech perception or word recognition performance (Humes et al., 1994).

In a large-scale study, a battery of tests of auditory performance, auditorily and visually presented tests of cognitive performance, and tests of speech perception and word recognition in quiet and noise were administered to various groups of older adults (van Rooij & Plomp, 1990, 1992; van Rooij, Plomp & Orlebeke, 1989). There were three major conclusions: (a) the primary factor associated with speech perception or word recognition performance was degree of pure-tone hearing loss; (b) cognitive measures accounted for a small additional proportion of the variance, especially for a group selected from the general public; and, (c) performance on cognitive tasks was not modality-specific. The results of van Rooij's group are, therefore, consistent with the results of Humes' group.

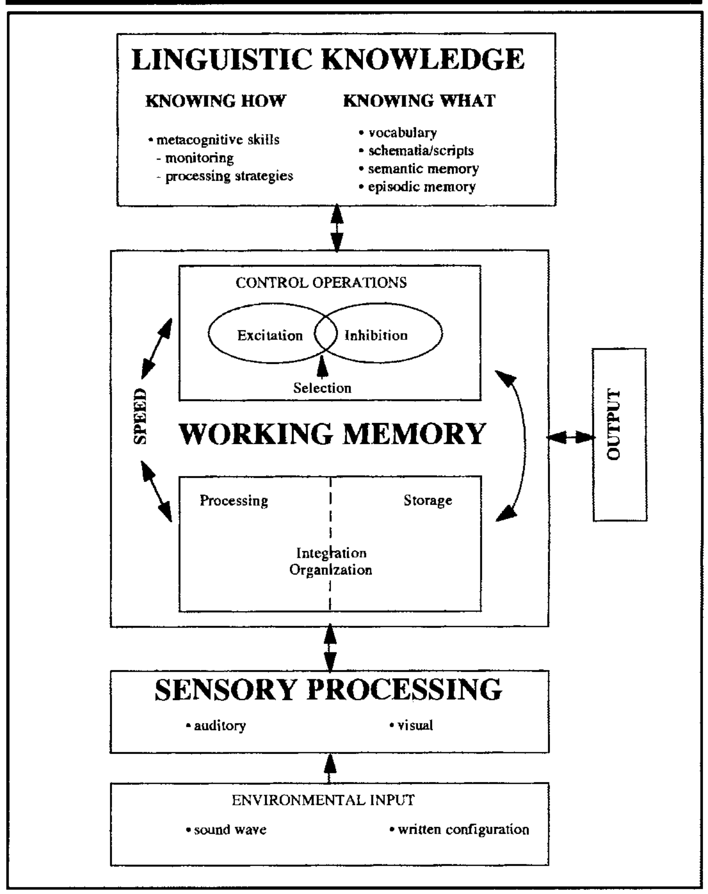
In a study to investigate the factors predicting word recognition performance, average pure-tone hearing loss was found to make a significant contribution to performance on monaural word recognition tests, and both pure-tone average and a cognitive measure of speed of processing were found to make a significant contribution to performance on dichotic tests (Jerger, Jerger, & Pirozzolo, 1991). The factors found to be related to monaural word recognition are consistent with the work of the Humes and van Rooij groups. However, the findings regarding central auditory processing in older listeners offer a different perspective. Jerger, Jerger, Oliver, and Pirozzola (1989) administered standard audiometric testing, standard neurospychological testing for cognitive impairment, and four tests of central auditory processing that use speech materials. Half of their sample demonstrated central auditory processing abnormalities but neither the standard audiometric nor neuropsychological measures could be used to predict central auditory processing status (see also Jerger, Mahurin, & Pirozzolo, 1990). These findings were later supported in studies using clinical and non-clinical samples (Stach, Spretnjak, & Jerger, 1990) and for four different age groups of older adults matched for audiometric thresholds (Jerger, 1992). Subsequent studies provided further evidence that the degree of handicap reported by older listeners and their communication partners is related to performance on measures of central auditory processing in ways that are not predictable from measures of pure-tone hearing loss (Chmiel & Jerger, 1993, 1996).

Overall, the work reviewed above indicates that pure-tone hearing loss is significantly correlated with performance on speech perception and word recognition tests. There are, however, several reasons why this account falls short of explaining why older adults have difficulty comprehending spoken language in everyday communication situations. First, the work of Jerger's group highlights the point that self-perceived handicap is related to performance on measures of central auditory processing but performance on these measures cannot be predicted from pure-tone audiometry. Second, older adults with no clinically significant hearing loss complain of difficulties comprehending spoken language in noisy everyday situations. Factors other than pure-tone hearing loss may contribute to their problems but fail to be found because the sampling strategy of the researchers is to include presbycusics with a wide range of hearing losses. Third, speech perception or word recognition tasks do not adequately represent the demands of true comprehension. Fourth, correlational studies do not provide evidence of causality.

The difficulty of interpreting correlational studies is illustrated by comparing the work reviewed above to that of cognitive psychologists who have modeled sensory and cognitive function in aging using correlations between measures of sensory acuity, specific aspects of cognitive performance (speed, reasoning, memory, knowledge, fluency), and general intelligence (Lindenberger & Baltes, 1994). The hearing researchers report sizable correlations between audiometric thresholds and measures of speech perception and word recognition, with little additional variance being accounted for by a selection of standard cognitive measures. Based on these findings, they attribute comprehension difficulties in older listeners to peripheral hearing loss. Cognitive psychologists also report large correlations between measures of sensory acuity (both visual and auditory) and general intelligence in a large-scale population study of older adults. Based on these findings, and noting that such large correlations are not found for younger adults, they propose a 'common-cause' hypothesis in which wide-spread, age-related, physiological deterioration occurs throughout the nervous system, simultaneously affecting many aspects of sensory and cognitive performance. They argue that the relatively large contribution of sensory acuity measures in accounting for age-related declines in general intelligence is due to the greater precision of these measures compared to measures of specific aspects of cognition. Thus, while researchers in both disciplines find strong correlations between measures of acuity and other speech or cognitive measures, their conclusions are quite different. Without a model of how perceptual and cognitive processes inter-relate during spoken language comprehension, even strong correlations between hearing and other measures provide no guidance regarding the functional nature of the relationship.

Although there is no single integrative one model available to us, we might gain insight into the relationship between age-related changes in perceptual and cognitive processes during comprehension if we try to reconcile the biophysical auditory system view of the problem with other models concerned with spoken language comprehension.

Figure 2. Cognitive information processing model as depicted by Kwong See and Ryan (1996).



Source: Kwong See & Ryan, 1996. Reprinted with the permission of the *Journal of Speech-Language Pathology and Audiology*.

A Cognitive Information Processing Model

In the companion Special Issue of *JSLPA* on "Aging and Discourse", Kwong See and Ryan (1996) reviewed evidence from cognitive aging research regarding the likely cognitive components of the language comprehension problems of older adults. The components considered include working memory capacity (see also Stine, 1990), inhibitory efficiency (see also Hasher & Zacks, 1988), and speed of processing (see also Cohen, 1987, 1988). Kwong See and Ryan (1996) based their model on a number of well-known models of discourse comprehension (Gernsbacher, 1990; Kintsch & van Dijk, 1978; Kintsch, 1988; Meyer, 1975; van Dijk & Kintsch, 1983; see also Stine, 1990). Their model has three main components: sensory processing, working memory, and linguistic knowledge (see Figure 2). Sensory processing is said to be "the junction between the external environment and higher-order cognitive operations" (p. 110). The working memory system includes two elements, one for control operations and the other for the processing and storage of information (see also Daneman & Carpenter, 1980). Speed of processing is depicted as a component because there is a proportional relationship between the speed at which processes take place and working memory capacity, although it is not clear whether slowing is a cause or a consequence of alterations in working memory capacity. The linguistic knowledge base in the model of Kwong See and Ryan (1996) might be described by others in terms of the sub-systems of long-term memory (Tulving, 1987). Overall, working memory acts as an interface between external input and stored knowledge.

Kwong See and Ryan (1996) concluded that age-related differences in the organization of linguistic knowledge at the lexical or script levels do not account for age-related differences in language performance. In contrast, age-related differences in comprehension are associated with declines in both the storage and processing functions of working memory (see also Garcia & Orange, 1996a; Ska & Joanette, 1996). For example, when processing and storage are simultaneously manipulated, older listeners have more difficulty than younger listeners with anaphoric reference; specifically, age-related differences increase as a function of the amount of discourse material intervening between the noun referent and the following pronoun (e.g., Light &

Capps, 1986). Other experiments to test the role of working memory in comprehension are concerned with the comprehender's ability to resolve ambiguity. In such experiments, there are no age-related differences in ability to activate multiple candidate interpretations (e.g., Balota & Duchek, 1988; Hamm & Hasher, 1992); however, old comprehenders continue to hold competing alternatives after young comprehenders have opted for the correct alternative and ceased holding incorrect alternatives in mind (Hamm & Hasher, 1992). The importance of processing speed has been demonstrated in experiments in which discourse material presented in speeded conditions was recalled better by younger listeners than by older listeners, with reduced recall reflecting reduced comprehension even though both age groups were able to correctly perceive the material that was presented (e.g., Stine & Wingfield, 1987).

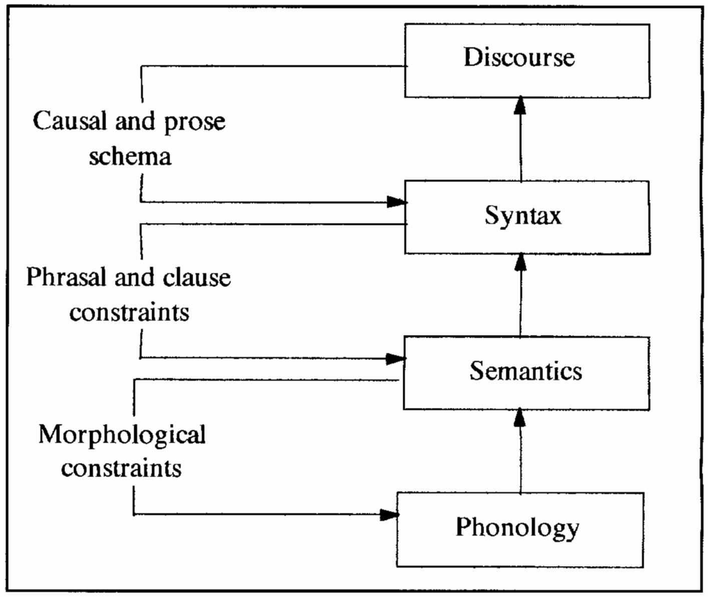
Correlational studies have also yielded evidence supporting the claim that much of the age variance in spoken language comprehension can be attributed to differences in working memory (e.g., Norman, Kemper, Kynette, Cheung, & Anagnopoulos, 1991; Tun, Wingfield, & Stine, 1991). Kwong See and Ryan (1995) found that older adults comprehended read text less well than younger adults, that they had poorer performance on working memory tasks, were less efficient at inhibiting irrelevant information, and were slower. On the basis of hierarchical regression analyses, they determined that each component was significantly correlated with language comprehension performance, and that when each component was entered into the regression before age there was a significant reduction in the variance that would otherwise have been attributed to aging. Based on the pattern of their findings, Kwong See and Ryan (1995) concluded that age-related differences in language comprehension were primarily mediated by the inhibition and speed components (for a critical commentary see Kahn & Goulet, 1996).

In contrast to the site-of-lesion orientation of the models used by hearing researchers, this kind of information processing model begins to provide us with a way of understanding the nature of the components (knowledge and mental operations) involved in comprehension and how they might be differentially affected by aging.

Psycholinguistic Models

Curiously, although our concern has been with how listeners comprehend language, in the two models presented so far, there was almost no mention of linguistic operations or the language system per se. In the auditory system model (Humes, 1996), the cortex has responsibility for information processing (presumably including linguistic operations), labeling (presumably including lexical access or word recognition operations), and storage (presumably including memory systems). In the cognitive informa

Figure 3. Psycholinguistic model as depicted by Kemper Anagnopoulos (1993).



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tion processing model of comprehension (Kwong See & Ryan, 1996), the component called linguistic knowledge refers to static knowledge, whereas the execution of linguistic operations is accomplished in the processing sub-component of working memory. Two questions emerge: (a) what kinds of linguistic operations are required for comprehension, and (b) how do these operations fit within a larger model that also includes auditory operations and cognitive operations? Psycholinguistic models may help us address these questions.

The nature of linguistic operations has been the domain of study of psycholinguistics for over 30 years. There is long-standing agreement that the linguistic system has sub-systems such as a phonological sub-system and a syntactic sub-system, with operations specific to each. However, there has been great debate over whether the linguistic system is autonomous (modular) with respect to other cognitive systems (following Fodor, 1982), or whether linguistic operations and other cognitive operations are interactive or non-autonomous (see Carpenter et al., 1995; Kemper, 1992). The model of Kemper and Anagnopoulos (1993) is one of the models that has been used in work on language processing and aging. In this model, processing proceeds from the phonologic level to the semantic level to the syntactic level to the discourse level (see Figure 3). In addition, higher level constraints may operate when processing at lower levels is stressed, thereby buffering the system as a whole in a compensatory fashion. Thus, the model is a weak autonomous model.

In the model (Kemper & Anagnopoulos, 1993), sub-systems are represented separately but stored knowledge and dynamic processing are not represented separately as they are in the Kwong See and Ryan (1996) model. The nature of the links between sub-systems is also not made explicit. However, the positioning of semantics between phonology and syntax in the model implies that word recognition is an important mediator between the different sub-systems, especially phonology and syntax (see also Kemper, 1992, p. 233). Because the work of hearing researchers has emphasized word recognition, the role of word recognition in linking linguistic sub-systems should be of interest to audiologists (see also Bernstein & Auer, 1996). By comparing models, we gain insights into the possible relationships between component sub-systems and the links between processes and stores of knowledge (see also Garcia & Orange, 1996a, 1996b).

In the case of elderly listeners, either those with clinically significant presbycusis or sub-clinical auditory processing problems, we would expect disruptions in the perception of the speech signal, with consequent disruptions of phonetic and phonologic operations (Cheesman, 1997). For presbycusics, reduced word recognition could jeopardize the links between linguistic sub-systems and these links may also be weakened by non-sensory effects of aging. For example, in her review of language and aging, Kemper (1992, p. 225) concludes that at least part of the age-related decrement in language processing may be due to age-related slowing of phonological processes (including articulatory and not just perceptual processes) and problems accessing lexical information on the basis of phonological (or orthographic) cues (e.g., Balota & Duchek, 1988; Bowles & Poon, 1985). Although declines in word recognition might be related to age-related changes in morphological processing, Kemper (1992, p. 233) notes that there has been no study of age-related changes at the morphological level of linguistic analysis.

Once words have been recognized, is there any evidence of age-related differences at the level of syntactic processing? Older adults produce less variable and less accurate syntactic structures, verb tenses, and grammatical forms, but with no age differences in lexical diversity or disfluencies related to the use of sentence fragments or lexical fillers (Kynette & Kemper, 1986). Kemper (1986) also found that older adults had more trouble repeating sentences with embedded clauses, especially longer, left-branching syntactic structures (e.g., Baking ginger cookies for my grandchildren tires me out. Kemper, 1992, p. 234), suggesting that their syntactic processing performance is compromised when many different syntactic operations must be performed simultaneously.

For listeners, the perception of speech segments is important for accurate word recognition which, in turn, assists accurate syntactic parsing. However, the perception of prosody also influences syntactic processing (Ferreira, 1993). It is important for audiologists to consider the role of prosody in spoken language comprehension by older listeners because it may remain largely intact even when loss of spectral information limits the accuracy of word recognition. In fact, prosodic patterns spanning clauses or sentences might even be represented in a revised model as a link between sound processing and syntactic processing that is not necessarily mediated by successful word recognition.

In experiments in which prosodic information and linguistic information were independently varied (by comparing three kinds of utterances: intact sentences, semantically anomalous but syntactically intact sentences, and scrambled strings that were neither semantically nor syntactically intact), elderly listeners demonstrated good use of prosodic information, especially in difficult listening conditions (Cohen & Faulkner, 1986; Stine & Wingfield, 1987; Wingfield, Lahar, & Stine, 1989; Wingfield, Wayland, & Stine, 1992). Importantly, when word recognition was stressed by speeding speech, older listeners with no clinically significant hearing loss used linguistic structure and content, including prosody, to even greater compensatory advantage than did younger adults (Wingfield, Poon, Lombardi, & Lowe, 1985; for a review see also Wingfield, 1996). Conversely, disruptions of prosody had more deleterious effects on the performance of older listeners.

Bromley (1991) found that, in the written language samples of adults aged 20-86 years, there were no age-related differences on lexical measures but older adults used less complex syntax, and vocabulary measures correlated with lexical performance but not syntactic performance. Similarly, compared to younger adults, in spontaneous conversations, adults aged 60-91 years produced shorter sentences with fewer clauses, more varied vocabulary, and more revisions and interjections (Walker, Hardiman, Hedrick, & Holbrook, 1981). Older adults living in nursing homes used shorter and less complex sentences, with more hesitations, including false starts and repetitions (Walker, Roberts, & Hedrick, 1988). Kemper (1992) cautions that the apparent age effects may be offset or exacerbated by other factors such as level of education and health. Overall, in these studies of syntactic productions, there is little or no evidence of lexical/semantic declines in older talkers, but there is some evidence of reductions in syntactic processing when processing demands are high. Extrapolating from these findings for talkers, we would expect an elderly listener, whose word recognition performance is jeopardized by age-related declines in hearing and slowing of phonological operations, to have even more difficulty when spoken syntactic structures are more complex.

In everyday life, listeners must build sentence comprehension into discourse comprehension. The integration of meaning across sentences is supported by discourse structures and linguistic cues that are not describable at the sentence level. At the discourse level, older adults benefit more than younger adults from content-related and structure-related contextual support (for reviews see the companion Special Issue of *JSLPA* on "Discourse and Aging" edited by Orange and Purves, 1996b; see also Kemper & Anagnopoulos, 1993; Wingfield, 1996). To give a few illustrative examples, age-related differences in comprehension are reduced when the comprehender has prior knowledge of the content (Dixon & Hultsch, 1983), when thematic information about the content of a script is available (Zelinski & Miura, 1988), or when more structured narrative discourse is used compared to when less structured expository discourse is used (Zelinski & Gilewski, 1988). The use of these kinds of context by hard-of-hearing listeners has often been discussed in the work of rehabilitative audiologists in terms of the synthetic (vs. analytic) abilities of speechreaders (Pichora-Fuller, 1996).

Prosody also provides supportive structure at the discourse level. For example, topic boundaries are marked by a rich combination of prosodic cues: gaps greater than three seconds separate the termination of one topic and the initiation of the next topic; topic initiations and terminations are cued respectively by increases and decreases in acoustical dimensions of speech such as intensity, rate, and fundamental frequency. Using such cues, regardless of degree of hearing loss, older listeners correctly identify topic boundaries when spoken monologues are heard in a range of levels of competing background noise (Pichora-Fuller, Tidball, Gilbert, & Kirson, 1996). As the level of the background noise increases, all listeners become slower in identify topic boundaries. However, older listeners are slower than younger listeners even in less noisy conditions; whereas young listeners usually identify the topic boundary before the new topic begins, the older listeners do not identify it until the new topic has already begun. Because topic terminations have low intensity compared to topic initiations, it could be that the older listeners do not hear the termination cues; however, even older listeners with near-normal audiograms are slower than younger listeners, suggesting that older listeners may simply require a fuller set of cues before they decide that the topic has changed.

Overall, the psycholinguistic approach highlights three different facets of comprehension in older listeners: (a) linguistic content and structure in spoken language depends on segmental and suprasegmental signal properties such that linguistic operations may be compromised by auditory processing problems; (b) modality-independent and impairment-independent findings suggest that older comprehenders have difficulty executing complex or multiple simultaneous linguistic operations at the level of various linguistic sub-systems, even in ideal perceptual conditions; and, (c) to a greater extent than younger listeners, older listeners make use of, and may need to rely on, supportive context or cue redundancy, especially when processing is stressed.

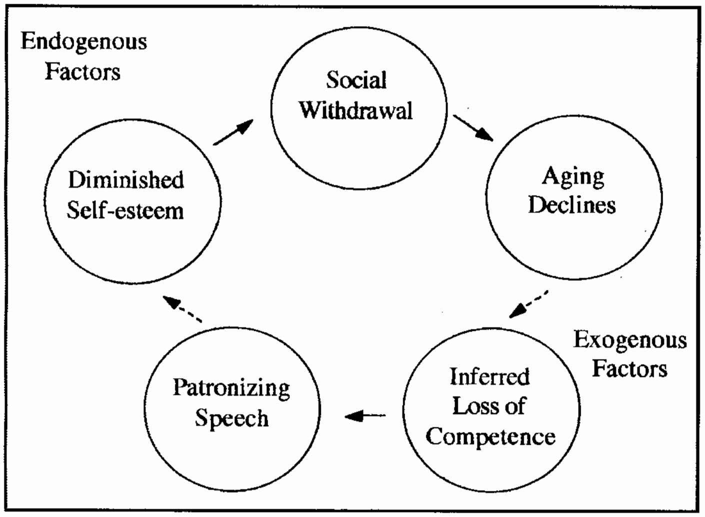
Social Psychology/Sociolinguistics Interpersonal Communication Predicament Model

In everyday life, the most common type of discourse is conversation. As Caplan (1992) points out, the pragmatic aspects of discourse, especially conversational discourse, require us to consider the attentional, intentional, and interpersonal aspects of communication. The discourse sub-system of a psycholinguistic model would differ from other linguistic sub-systems because of the necessity of linking with stored knowledge and other aspects of cognition that are not strictly linguistic (Caplan, 1992, p. 361). Up to sentence-level processing, we need only think of the listener decoding the utterance. At the discourse-level of processing, we must think of the listener decoding and simultaneously formulating responses to linguistic and other behaviours of communication partners. Therefore, it becomes necessary to consider how social factors affect comprehension.

Psycholinguistic models of discourse processing have been developed for text comprehension by readers (e.g., Kintsch, 1988; Kintsch & van Dijk, 1978; van Dijk & Kintsch, 1983), and for more interactive spoken discourse (e.g., Grosz, Pollack, & Sidner, 1989; Grosz & Sidner, 1986). However, few psycholinguistic studies have investigated the conversational behaviours of older adults. In their review in the companion special issue of *JSLPA* on "Discourse and Aging", Garcia and Orange (1996) reported that in one study, no age differences in the use of pragmatic information were found unless the stimuli overwhelmed working memory processes (Light & Albertson, 1988). Garcia and Orange (1996, p. 127) conclude that there is little evidence that older conversationalists have problems encoding topics although they may experience difficulty retrieving detailed information pertaining to topic, with this difficulty suggesting working memory problems and/or attentional problems related to an inability to inhibit information already stored in memory.

The interpersonal interaction model of Ryan et al. (1986) features more of a psycho-social than a psycholinguistic approach. In particular, it depicts how the immediate and long-term communication performance of older listeners might be influenced by communication experiences. Figure 4 depicts the communication predicament of aging in which the negative, stereotyped reactions of communication partners give rise to a kind of self-fulfilling prophecy whereby the communicative performance of the older communicator is reduced to the level that was expected (Ryan et al., 1986; Ryan, Meredith, MacLean, & Orange, 1995). The cycle begins when conspicuous signs of aging (e.g., physical appearance, voice quality, wearing of a hearing aid, social role and living situation) cue communication partners to expect diminished communication competence. In turn, these expectations often result in aberrant interactional patterns between the communication partner and the older person (e.g., patronizing speech and language). These aberrant communication experiences may ultimately give rise to actual loss of self-esteem and confidence by the older communicator. Eventually, social interaction may be avoided, leading to actual deterioration in communication ability. Thus, there may be immediate

Figure 4. Interpersonal communication predicament model adapted from Ryan et al. (1986).



Source: Ryan et al. (1986). Reprinted with permission from Elsevier Science Ltd., The Boulevard, Langford Lane, Kidlington, OX5 1GB, UK.

and long-lasting alterations in communication resulting from interpersonal factors, and these factors may combine with intentional and attentional factors (see also Garcia & Orange, 1996a, 1996b; Palm & Purves, 1996; Ryan, 1996).

Garcia and Orange (1996a, p. 127-128) identify several sociolinguistic and psychosocial issues that have been investigated regarding the conversations of older adults: (a) establishing and retaining a sense of self and social identity; (b) creating and maintaining relationships; (c) partner and context-dependent influences; and, (d) the social actions of communication. Accommodation theory has been useful in exploring many of these issues. According to accommodation theory (Coupland, Coupland, & Giles, 1991; Coupland, Coupland, Giles & Henwood, 1988), social factors influence how talkers modify their speech, language and non-verbal behaviours depending on the communication partner. The notion of over-accommodation in the communication predicament model (Ryan et al., 1986) extends this idea to the case where communication patterns are adversely affected by negative ageist stereotyping. Over-accommodation of this type has been called elderspeak. Elderspeak has characteristics reminiscent of babytalk including simplified grammar and semantic content of language, prosodic distortions of speech such as slowed rate, exaggerated pitch contour, and increased loudness, as well as nonverbal behaviours such as reduced eye contact, inappropriate proxemics, and finger and/or toe tapping (Garcia & Orange, 1996a).

Some of the behaviours typical of elderspeak are endorsed by rehabilitative audiologists as effective communication strategies (e.g., slowing speech rate), while others (e.g., reduced eye contact) would be considered maladaptive. Kemper (1992) recognized the need to differentiate the aspects of accommodation that enhance comprehension from those that do not. Recent findings (Kemper, 1996) support the conclusion that some of these behaviours help, while others actually undermine comprehension. Furthermore, the use of over-accommodating behaviours, even those that are helpful when warranted, may jeopardize social interaction and maintenance of self-identity and self-esteem in older adults when they are triggered by ageist stereotypes rather than actual need for accommodation (e.g., Baltes & Wahl, 1996; Baltes, Wahl, & Reichert, 1991). Interestingly, intergenerational communication is characterized by such potentially damaging over-accommodating behaviour more so than is intragenerational communication (Garcia & Orange, 1996a). Importantly, whereas audiologists believe that accommodating behaviour will foster greater communication success and therefore promote independence and maximize social participation, over-accommodating communication patterns can reinforce dependency and minimize social roles.

Garcia and Orange (1996a) also review studies of off-topic verbosity, or negatively perceived loquaciousness, that is thought to increase with age (see also Kemper, 1992, p. 231). Off-topic verbosity has been reported to be independent of hearing loss (Gold, Andres, Arbuckle, & Schwartzman, 1988), yet audiologists commonly attribute similar behaviours in hard-of-hearing people to the fact that they chose to talk in order to avoid listening. A common thread in both accounts is the apparent difficulty of the communicator in dividing attention or balancing the allocation of mental resources to the double roles of talker and listener; however, the possibility that the same behaviour may be attributed either to aging or to hearing loss raises issues about the assessment and remediation of these behaviours.

Overall, the sociolinguistic and social psychology work highlights the need for audiologists to re-think the potential usefulness and practicality of communication strategies for hard-of-hearing seniors, and introduce considerations of communication etiquette into rehabilitation planning. In considering communication etiquette, an audiologist would evaluate the social significance, and acceptability of the recommended communication strategies, for elderly hard-of-hearing individuals and their communication partners (see also Ryan et al., 1995).

Non-autonomous Working Memory Model of Language Processing

So far, we have reviewed models proposed from the points of view of researchers in different disciplines concerned with how older listeners comprehend language. Each model has focused primarily on one of the many important aspects of processing involved in comprehending conversation: auditory processing, cognitive processing, linguistic processing, and pragmatic/social information processing. Our difficulty remains how to reconcile the models. There are four necessary requirements for comprehension: external cues arising from sources in the world; activation of internally stored knowledge of content and procedures; processing or execution of sets of operations to map, or compute, the relationship between the internal and external sources of information; and time or timing or capacity limits on this processing. While these basic requirements seem obvious, what is less obvious is how we should conceptualize the functional and temporal coordination of the multiple operations that must take place during comprehension to accomplish the mapping between externally produced stimuli and internally stored knowledge (Carpenter et al., 1995).

To recap, older comprehenders have difficulty hearing speech cues. Communication partners may alter speech cues, further reducing the quality and quantity of useable external information. Whereas the availability of external cues is reduced, internally stored knowledge is preserved with respect to all domains studied, including linguistic, social, and general world knowledge. However, processing at all levels is altered, with older listeners having greater difficulty executing perceptual, linguistic, and cognitive operations. The consequences of processing difficulties at the perceptual level may cascade, negatively affecting subsequent processing at higher levels (Pichora-Fuller, Schneider, & Daneman, 1995). Furthermore, older listeners are less successful in executing multiple operations within a limited capacity/time or with sufficiently precise timing. For example, according to Carpenter, Miyake, and Just (1994, p. 1104), "results suggest that reduced working memory resources in elderly adults may limit their capabilities to simultaneously retain, monitor, and manipulate structurally complex sentences in working memory." This is presumably why errors and/or slowing in comprehension are observed in more challenging conditions whereas comprehension difficulties are not so apparent in less challenging conditions. In more challenging conditions, comprehenders may need to resample external cues or internal knowledge sources, or even shift the allocation of processing resources to priority operations in order to compensate for the loss of particular external cues. The working memory model of Carpenter and her colleagues (Carpenter et al., 1995) offers an approach that may guide us in assembling these pieces of the puzzle to form an overall picture.

Carpenter and her colleagues (Carpenter et al., 1995) propose a hybrid symbolic-connectionist computational model of language comprehension that combines the strengths of two different approaches to modeling language. One approach is a symbolic, or rule-based approach, that can be used in a straightforward way to express computations (e.g., syntactic parsing rules). The other approach is a connectionist approach in which there is a network of linked nodes that integrate and propagate activation through excitatory and inhibitory links such that various levels of activation at nodes correspond to graded representations. The symbolic approach is well suited to specifying computations; the connectionist approach is well suited to specifying the time course of parallel processing or computations in terms of gradual activation and suppression in the network.

Such a hybrid model can be used to model the role of speed of processing in a way that was not attempted in the more general cognitive information processing model (Kwong See & Ryan, 1996), the psycholinguistic model (Kemper, 1992), or the auditory system model (Humes, 1996). Also, note that the cognitive information processing model described earlier (Kwong See & Ryan, 1996) assumes control operations (following Baddeley, 1986) that are necessary to coordinate modular cognitive subsystems (including linguistic subsystems). In contrast, the non-autonomous view (Carpenter et al., 1995) claims that there is continuous interaction among sub-systems, with the coordination of the subsystems accomplished by graded changes in level of activation instead of control operations. Specifically, three principles underlying general cognitive mechanisms are set forth in the model: (a) gradedness of information in representations (stages of construction and decay); (b) gradedness of processing (spreading activation/suppression); and, (c) resource constraint (Carpenter et al., 1995, p. 115). "The constraint on capacity is operationally defined as the maximum amount of activation that the system has available conjointly for maintenance and processing purposes. The capacity limitation is realized under an allocation scheme that has the potential to trade off between maintenance [storage] and processing" (Carpenter et al., 1994, p. 1091). The Carpenter model suits our purpose of trying to understand how older listeners balance or trade reduced external information against preserved internal knowledge during the course of mapping the link between signal and meaning.

In what way can this model help us to understand how older listeners' comprehension varies as a function of listening condition and how the reallocation of processing resources in challenging listening conditions may sustain comprehension? In ideal listening conditions, external and internal information sources are rich and readily accessed, activation thresholds are achieved quickly, multiple processing operations are executed with no difficulty, and comprehension is highly accurate and relatively effortless. Under these conditions, the limited capacity of working memory is not exceeded. In contrast, when external cues are impoverished or perceived less accurately, when activation thresholds are achieved slowly, when it becomes difficult to execute some processing operations either because the required input is reduced or because the operations themselves are compromised, or when there are too many operations required in too short a time, then the limited capacity of working memory becomes overloaded. In such conditions, resampling or reallocation of working memory resources must occur or else comprehension will fail.

Assume there are three different zones of listening conditions: (a) conditions in which comprehension is effortless (working memory capacity is not saturated by processing demands in establishing the signal-meaning correspondence); (b) conditions in which comprehension succeeds but processing is effortful (working memory capacity would be exceeded if resource reallocation or slowing were not implemented; processing economy is crucial); and, (c) conditions in which comprehension fails (resource reallocation or slowing of processing cannot be implemented in a fashion that is sufficient to achieve the mapping of signal-meaning within working memory limitations; recovery from failed operations cannot be achieved).

It should be important to audiologists to find out how older listeners perform in a range of conditions so as to determine those conditions in which comprehension begins to go wrong and those in which it fails, and how listeners reallocate resources by resampling external or internal information sources (using context) or reprioritizing processes to achieve processing economy when comprehension is effortful. Relevant findings come from experiments in which input is graded to stress perceptual or linguistic processing and the availability of different types of context is graded. Two ways of grading speech input are to vary the speed of presentation or to vary signal-to-noise ratio (S:N). In such studies, word recognition performance is measured as well as memory for, or comprehension of, what was heard.

The three zones of listening conditions are captured to some extent in experiments using time-compressed speech (Wingfield, 1996). In the first zone, at normal speech rates (140 to 180 words per minute), listeners with near-normal audiograms experience effortless listening because signal information is sufficient to establish the signal-meaning map without reliance on contextual support beyond the target word. In the second zone, with rates varying from 275 to 425 words per minute, as speed increases word recognition relies more and more heavily on supportive context and listening becomes effortful. In the third zone, at extremely fast speech rates, word recognition would, no doubt, totally fail but these limits have not been tested.

Age-differences in word recognition when speech is time-compressed depend on the content and structure of the utterances, such as propositional density (Tun, 1989), syntactic intactness (Wingfield et al., 1985), and naturalness of prosody (Cohen & Faulkner, 1986; Stine & Wingfield, 1987; Wingfield et al., 1989; Wingfield et al., 1992). Age differences also depend on whether or not preceding or following supportive context is available (Wingfield, 1996). Younger and older listeners both recognize words better as the amount of preceding context is increased; however, younger listeners benefit more than older listeners from context following an acoustically ambiguous target word (Wingfield, Alexander, & Cavigelli, 1994). These findings are consistent with other studies in which old adults were more influenced than young adults by "expectedness" based on long-term or recently stored knowledge when making inferences or assigning referents to pronouns in discourse (e.g., Kahn & Cordon, 1993; Ska & Joanette, 1996).

Using a speech shadowing task in which listeners repeat verbatim (immediately recall) what they hear and are free to pause the recording as often as they need to, younger and older listeners choose to listen to chunks of the same size, but older listeners have poorer immediate recall in more stressed time-compression conditions (Wingfield & Butterworth, 1984; Wingfield & Lindfield, 1995). Similarly, when presented with long sentences at faster than normal rates, immediate recall (shadowing) declines more markedly for older than for younger listeners, even when the older listeners have higher verbal ability and more education (Stine, Wingfield & Poon, 1986). In addition, during shadowing, compared to younger listeners, older listeners are slower in performing a simultaneous reaction time task, especially when the task (choice vs. simple reaction time) is more complex (Tun, Wingfield, & Stine, 1991). These findings suggest that older listeners allocate relatively more resources to processing input and that the span of input that can be remembered accurately is more limited for them than for younger adults. While older listeners may be as good or better at using contextual support from long-term stored knowledge or from recently processed prior information, the "time window" of the ongoing or upcoming signal that they can effectively map to meaning seems to be narrowed, at least when disambiguation is required in stressed perceptual conditions. In other words, in stressful listening conditions, the trading of input versus stored information is tipped in favour of greater use of input cues by younger adults and in favour of greater use of stored knowledge by older adults.

In studies of word recognition in a range of S:N conditions, older adults with near-normal audiometric thresholds performed similarly to younger adults when listening to words in sentences or discourse so long as the S:N was about 6 dB higher for the older listeners (Pichora-Fuller, Dillon, Howarth, Gilbert, & Lee, 1996; Pichora-Fuller et al., 1995). Therefore, apparent age-related differences are largely eliminated by providing older listeners with a S:N advantage. As in the studies using speeded speech (Wingfield, 1996), when the S:N condition is unfavourable, older listeners benefited more than younger listeners from prior sentence or discourse context. For presbycusic listeners, without supportive context, word recognition never reaches 100% in any S:N condition; however, with the benefit of supportive context, they can achieve perfect performance if the S:N condition is sufficiently favourable (Pichora-Fuller et al., 1995). Put another way, older listeners with relatively good audiograms enjoy effortless listening if the S:N condition is favourable; however, presbycusics never experience conditions of effortless listening and must always rely on context.

Consistent with the findings for speeded speech, even when words heard in noise are recognized, they are remembered less well and are presumably less available to be integrated into meaning structures during comprehension. In one study, young adults recalled fewer correctly perceived digits and they remembered fewer details of short passages of discourse when materials were presented in noise compared to when they were presented in quiet (Rabbitt, 1968). In another study, working memory span decreased for both young and old adults as S:N decreased (Pichora-Fuller et al., 1995). A subsequent study of how words heard in noise are recognized and remembered, with and without supportive visual speech cues (speechreading), replicated the original finding of a decline in recall with increased perceptual stress, and it also demonstrated how bimodal perceptual support offsets the declines in recall observed in conditions of competing noise (Pichora-Fuller, 1996). Rabbitt (1991) proposed that effortful listening affected memory by undermining rehearsal, elaborative encoding, and deep processing of material heard in noise by the hard of hearing, even when word recognition was highly accurate. Thus, if processing resources must be allocated to the recovery of a speech signal that is difficult to encode, there could be fewer resources available for processes crucial to the deeper and long-lasting comprehension of running speech, such as the important task of integrating currently heard material with past knowledge.

In grappling to account for the widely acknowledged fact that older listeners have difficulty comprehending spoken language in everyday situations (Pichora-Fuller & Cheesman, 1997), comprehension has been conceptualized here simply as the mapping of an external signal to internally constructed and stored meaning. For most speech signals there is abundant redundancy, with the consequence that there is not just one way to successfully map the signal to meaning. Rather, there are many alternative routes that may succeed.

A clear demonstration of the multiplicity of cues that may support comprehension, the mapping of input to meaning, is provided by speechreading phenomena. For a normal young adult listener, acoustic speech cues are unambiguous in quiet conditions and comprehension based on the perception of acoustic speech cues is usually effortless. For the same listener, the same speech signal becomes ambiguous in adverse S:N conditions. In order to disambiguate the acoustic speech signal to achieve comprehension, perceptual processing shifts to the less effortless, but nevertheless remarkably effective, use of bimodal speech cues (Massaro, 1987). Audiologists have a long history of interest in the 'analytic' and 'synthetic' abilities or styles of speechreaders, where analysis refers to heavier weighting of signal or bottom-up cues to achieve disambiguation, and synthesis refers to heavier weighting of contextual or top-down cues (Pichora-Fuller, 1996). It seems useful to think similarly of older listeners who, due to sub-clinical or clinical changes in auditory processing, frequently encounter signal ambiguity, especially in the noisy and reverberant environments typical of everyday real-world listening conditions. In such effortful listening conditions, listeners are often able to overcome ambiguity and achieve a successful mapping between signal and meaning, but the mapping will often rely on contextual redundancies derived from prior input or from world knowledge. Importantly, a variety of successful solutions or routes to map signal to meaning may be manifested. The acceptability and availability of different solutions to the problem of mapping ambiguous input to meaning will also be governed by the purpose or goal of the communication, and be related to the task and the participants themselves (for a discussion of the importance of text, task and comprehender factors in discourse processing see Ska & Joanette, 1996). It is necessary to begin to specify how processing resources can be economically reallocated to different processing options when comprehension is at risk in conditions of ambiguity, because the demands of disambiguation may exceed the listener's working memory capacity.

Reconciling the Models

In trying to reconcile the models that have been considered, it seems important to recognize that a common theme is that there are age-related and also pathology-related differences in the availability and use of various kinds of redundancy by comprehenders. Studies of perceptual coding of the acoustic signal provide evidence of age-related changes in auditory processing that reduce the richness of the input cues available to listeners, even though these abnormalities may or may not be considered to be clinically significant in present audiologic practice (Cheesman, 1997; Schneider, 1997). These auditory abnormalities tax perceptual processing and there is every reason to believe that, in turn, higher cognitive processes are also taxed (Pichora-Fuller et al., 1995).

In the face of impoverished external input and difficulties in perceptual processing of this input, the older listener becomes more reliant on the use of context and internally stored knowledge. Word recognition and local comprehension may succeed because the redundancy afforded by context offsets the loss of signal information; however, the use of such alternative processing routes is likely to result in weaker activation of the words that are recognized. In effortful listening conditions, activation may exceed the threshold level for word recognition but, compared to the pattern of activation characteristic of word recognition in effortless listening conditions, threshold may be reached more slowly, activation level may only barely exceed threshold, and/or activation may be less precisely tuned to the target word with diffuse activation of other likely alternatives. In this way, change in the strength and precision of activation and the shift to more computationally demanding alternative processing routes could enable recognition of what was heard but weaken memory for, or subsequent processing of, what was heard, with relatively rapid loss of the information that has been heard, and possibly with an ultimate failure in global comprehension of discourse (see also Wingfield & Lindfield, 1995).

For listeners with richer knowledge stores, or listeners with greater working memory capacity, even when some of the details of the communication are sacrificed (either not heard or not remembered), gist may still be comprehended. The fact that individual differences in comprehension have been related to education and verbal ability is consistent with the idea that there is an age-related shift in the relative contributions of internally stored knowledge versus information derived from external input, with more successful older comprehenders being especially advantaged because of the richness of their stored knowledge and consequent greater success in shifting the relative weighting of internal over external information. For example, Dixon, Hultsch, Simon, and von Eye (1984) found a three-way interaction of age, verbal ability, and propositional level: high-verbal older adults comprehended main ideas as well as younger adults but they had more difficulty than younger adults comprehending details carried in low-level propositions; low-verbal adults performed more like younger adults in comprehending details but they comprehended main ideas much more poorly.

Accepting that there are individual differences, studies of linguistic knowledge and operations nevertheless suggest that long-term stored knowledge is well preserved in older comprehenders, but that there may be abnormalities in their execution of linguistic operations. Referring to the linguistic system, Kemper (1992, p. 250) suggests that "older adults may be able to compensate for low-level deficits through the use of high-level knowledge schemata". Therefore, in addition to age-related differences in auditory processing, normal older listeners may also have difficulty executing linguistic operations when processing demands are high (see also Zurif, Swinney, Prather, Wingfield, & Brownell, 1995).

It seems that by stressing the processing of input (at the level of perceptual or syntactic operations), these comprehenders, especially those who have lower working memory spans, require greater processing resources than may be available. The notion of processing resources corresponding to amount of brain activation has been pursued in a recent study of "thinking hard", in which it was shown that the amount of neural activity in the brain depended on the computational demand imposed by the task (Just, Carpenter, Keller, Eddy, & Thulborn, 1996). Such a change in amount of brain activation with task demand also seems to be compatible with the idea that in conditions of effortful listening ambiguity is resolved by recruiting other sources of informational redundancy that would not need to be recruited in effortless listening conditions.

For conversation, on the one hand, its interactive nature offers contextual support derived from knowledge of conversational behaviours such as turn-taking and from cues provided by the conversational partner; on the other hand, conversation may also increase processing demands because the listener must simultaneously attend to both the linguistic and social cues provided by the talker and simultaneously listen while planning productions to be uttered in an upcoming turn. With such complex, competing demands, the importance of prioritizing processes and economically and effectively reallocating resources becomes obvious (see also Palm & Purves, 1996).

Given this account of the comprehension difficulties of older listeners, we should now return to consider the hypotheses of the CHABA (1988) report, namely that these difficulties may be due to changes in peripheral hearing, central hearing, or cognition. The work of hearing scientists has supported the significant contribution of changes in peripheral hearing to what they call speech understanding. It seems obvious within the working memory account that I have developed here that the unquestionable age-related changes in auditory processing will, in turn, stress higher-level cognitive processes that are involved in mapping the signal to stored knowledge. The very nature of comprehension processes is necessarily altered if perception is stressed — the listener has to think harder. This alteration in the allocation of processing resources may result in failed comprehension even when the signal has been correctly recognized. While crediting the importance of age-related changes in auditory processing, it seems less useful to adopt the traditional differential diagnosis, or site-of-lesion approach, than to adopt an integrated processing approach in modeling the comprehension problems of older listeners.

While audiometric thresholds may correlate strongly with word recognition ability and demonstrate the important contribution of the auditory periphery, these studies shed no light on the relationship of auditory or cognitive measures to true comprehension. To test the ability of listeners to comprehend it would also be necessary to determine whether the listener correctly executes linguistic operations and integrates the words that are recognized with prior information or stored knowledge to construct the meaning of what was heard, sometimes with the additional requirement that this constructed meaning be deployed in conversational interactions in which the mapping of social signals to meaning may further alter information processing load.

Implications for Aural Rehabilitation for Older Adults

This overview has clear implications for rehabilitative audiologists. Beyond using technology to try to optimize hearing, rehabilitative audiologists must consider how to ease listening.

When listening is made easier, older listeners comprehend and remember heard material better and satisfying social interactions are more likely to be preserved. While traditional technological interventions have focused on the hard-of-hearing person, it is obvious that ease of listening will also be determined by the clarity of the speech signal produced by the talker, and the acoustical and visual properties of the communication environment. Moreover, ease of listening will be enhanced if the structure and content of the message and situation provide a high degree of contextual support that can be used to offset unavailable signal cues. In effect, ease of listening can also be expected to vary with the goals or tasks of both the hard-of-hearing communicator and his or her partner(s), and the extent to which the communication is motivated by information giving, information getting, or social interaction. Therefore, beyond the traditional focus on the hard-of-hearing person, there is good reason for rehabilitative audiologists to diversify their interventions in the following directions: (a) optimizing the clarity of signal transmission by training talkers to produce clear speech, implementing modifications to physical environments, and selecting technologies to enhance S:N; (b) training both hard-of-hearing communicators and their communication partners to maximize supportive context and its use; and, (c) training both hard-of-hearing communicators and their partners to make conscious decisions regarding when it is important for them to expend the mental energy required for thorough comprehension, including the economical use of repair strategies. The work outlined in this review should stimulate new ideas about how to grade therapy exercises aligned with these directions for further program development. Examples of recent attempts by Canadian rehabilitative audiologists to implement some or all of these considerations in practice are provided in the programs described in Part II of this issue.

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Endnotes

1. Following the definitions of the World Health Organization (see WHO, 1980; for an application to audiology see Hyde & Riko, 1994), impairment is defined as a physical, physiological, or anatomical loss or abnormality of function (for example, loss of outer hair cells in the cochlea), disability is defined as the loss or reduction of normal ability resulting from impairment (for example, difficulty perceiving speech), and handicap is defined as the detrimental effect that the disability has on an individual's life, especially on the activities and roles he or she normally performs.

2. Listening and comprehension are complex activities affected by external factors such as the relationship between the participants, the participants' listening (and interaction) goals, their level of interest in what is being said, their attention at a particular moment, and so on. Although there is no agreed upon definition of listening, researchers do agree that there are different kinds of listening (critical vs. empathetic listening, for example), and that component skills can be identified and even tested (Ridge, 1993). Skills enumerated in various definitions of listening typically include perceiving, attending, and interpreting, and (less frequently) memory and response. Each of these is a category of more specific skills (e.g., interpreting includes recognizing main points, making inferences, determining literal vs. symbolic meaning, apprehending the talker's intent, etc.). The listener must also have a listening strategy, which allows her to use contextual (including cultural) knowledge to select and employ the particular skills appropriate in the current listening situation; according to Ridge, both skills and strategies are part of an individual's listening competence. The point is that hearers, in addition to perceiving the sounds of a message, actively use their linguistic, social, and world knowledge to apprehend both the signal and the many features of the context in which it is embedded to interpret the message (see also Milroy, 1986).

3. Humes (1996, p. 161) defines speech understanding as "a general term for the proportion of a speech signal that is accurately perceived by a listener whether in a discrimination, identification, recognition, or comprehension paradigm". At first glance, such generality may seem to be advantageous because it does not limit the paradigm of investigation. However, Humes (1996, p. 161) freely substitutes the term "speech-recognition difficulties", and the paradigms that have been employed in this research have included discrimination, identification, or recognition paradigms but never a comprehension paradigm. After all, the term speech understanding has been applied narrowly and this usage obscures the fact that highly accurate perception of the speech signal (including same-different discrimination between two tokens, identification of tokens according to closed-set category membership, or naming of tokens recognized in an open-set) may be neither sufficient nor necessary for highly accurate comprehension of the meaning of spoken language. The input signal received by the listener originates from an external source and it must be matched with internal knowledge for meaning to be derived from a communication — for a listener to have comprehended what was said by a talker. It is not the accuracy of the perception of the signal per se but rather the formation or construction of meaning when the externally produced signal is matched with internal knowledge that is in question. Therefore, the terms speech perception and comprehension of spoken language are preferred to the less specific term speech understanding.