THE EFFECTS OF AGING AND TIME DISTORTED SPEECH MATERIAL ON SHORT-TERM MEMORY PERFORMANCE

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Abstract

Many age-related changes in perception and cognition have been reported. Well documented is a decrease in several aspects of perceptual as well as cognitive processes. In fact, perceptual and cognitive processes are largely correlated in older adults. This led to the suggestion that changes in perception may cause changes in cognition. Studies testing this hypothesis demonstrated that when younger and older adults were equated for the degree of perceptual stress age-differences disappeared on several cognitive tasks. Indeed, when listening situations have been equated it appears that the ability to use linguistic knowledge and context improve with age (Pichora-Fuller, Schneider, & Daneman, 1995; Speranza, Daneman, & Schneider, 2000). In order to compensate for age-related losses older adults are believed to develop certain skills and to reallocate available processing resources. In the present study younger and older adults were equally perceptually stressed by manipulating the temporal aspects of speech in a paired-associate recall paradigm of unrelated words. Twenty-five younger and 25 older participants were tested in two experiments. Adjusting for perceptual stress along a temporal dimension did not eliminate age-differences in cued-recall such that a decline of memory performance with age was observed. Indeed, temporal distortion did not contribute to the age differences in performance. The results are compared to similar studies in which babble and white noise were presented to equate perceptual stress. Differences in performance across studies are interpreted in terms of perceptual learning and the reallocation of processing resources.

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Introduction

As people age, a number of studies has shown that auditory and visual abilities are highly correlated with cognitive functioning (Lindenberger & Baltes, 1994; Baltes & Lindenberger, 1997; van Rooij & Plomp, 1990; 1992). Indeed, the correlation between perceptual declines and cognitive declines increases with age (Lindenberger & Baltes, 1994; Baltes & Lindenberger, 1997). In combination vision and hearing account for 49.2% of the total and 93.1% of the age-related variance of cognitive performance (Lindenberger & Baltes, 1994; Baltes & Lindenberger, 1997). In the elderly, vision and hearing are better predictors of cognitive performance than the total number of years of educational training (Lindenberger & Baltes, 1994).

The correlation between perceptual and cognitive abilities suggests the possibility that age-related changes in perception may be responsible for age-related changes in cognition. Evidence for this can be found in experiments by Humes and Christopherson (1991) who showed that when adjusting the level of masking noise at each frequency to produce a threshold elevation in normal subjects that matches those of presbycusics, young listeners perform equally to old listeners on monaural identification tasks. A similar result was found by Schneider, Daneman, Murphy, and Kwong See (2000), who presented stories or lectures in quiet or noise to their subjects. After hearing the material, the subjects had to answer questions about the content. When the listening situation was altered to produce a comparable perceptual stress in young and old adults, age-related performance differences in cognition were minimized. However, Murphy, Craik, Li, and Schneider (2000) found that performance differences between young and old adults could not be completely eliminated in a paired-associates memory task when younger and older adults were equated in terms of perceptual stress. Hence, when the hearing conditions are adjusted to make it equally difficult for younger and older adults to hear individual words, age differences disappear on many, but not all cognitive tasks. The reasons for this difference across tasks need to be experimentally explored. In particular, we need to know the extent to which cognitive rather than perceptual changes are responsible for the remaining differences in some of the tasks.

It should also be noted that there are studies which suggest that some cognitive abilities remain stable or even improve as people age (Wingfield, 1996). For example, it has been shown that older adults maintain excellent levels of language processing capabilities (Light, 1990). The paradox of improvement in some abilities coupled with decline in others has been accounted for by the hypothesis of compensation (Salthouse, 1987). According to this hypothesis older adults tend to find ways to compensate for age-related losses (Baeckman & Dixon, 1992; Baltes, 1987). It is assumed that although older people lose some facility in certain aspects of skilled behavior, they gain facility in other aspects which helps them to offset the losses. This hypothesis has been supported by Pichora-Fuller et. al. (1995) who demonstrated that older adults were better able than younger adults to use context to disambiguate words they could not hear properly. Thompson (1995) reported that the mechanisms of compensation also work the other way so that perceptual processing sometimes can compensate for declining cognitive processes. In her study older participants tended to rely more heavily on visible speech cues in an immediate recall memory task to compensate for deterioration in working memory ability. In general, while auditory abilities decline with age, some cognitive abilities do while other do not.

Moreover, compensatory mechanisms can often be engaged to offset both perceptual and cognitive declines. In the following the evidence and theoretical accounts for the relationship between cognitive aging and perception are reviewed. Evidence for cognitive age-related changes and three theoretical frameworks to fit the data mainly of cognitive decline are discussed first. Following this, perceptional changes in hearing and especially age-related changes in the temporal aspects of hearing will be reviewed.

Cognition and Aging

Evidence for Age-related Cognitive Changes

Age-related decline in many processes of cognitive functioning has been well documented (Charness & Bosman, 1990; Plude & Hoyer, 1985; Salthouse, Kausler, & Saults, 1988). Thus, it is not surprising that older adults perform less well on episodic memory tasks of all types (Denney & Larson, 1994). Verhaeghen, Marcoen, and Goossens (1993) conducted a meta-analysis of 180 studies on episodic memory, 21 of which followed a paired associate design. They calculated that the memory performance of an average older adult is situated at the 18th percentile of a young adult for paired-associate recall. The meta-analysis led Verhaeghen et. al. to the conclusion that age differences in memory performance are large and omnipresent. They found almost no condition in which age differences were not significant.

Among the cognitive processes that decline with age are encoding processes (Rabinowitz, Craik, & Ackerman, 1982), attentional processes (Plude & Hoyer, 1985), working memory capacity (Foos, 1989), comprehension of discourse (Light & Albertson, 1988), and interference formation and interpretation (Cohen, 1979, 1981).

On the other hand, there are a few processes that show no decline or even an improvement with age as shown by Pichora-Fuller et. al. (1995). They presented their participants with auditory information and reasoned that when the processing of the auditory information is compromised by age-related changes in peripheral processing then the input to the cognitive system is an ambiguous or distorted speech signal. Part or all of the information lost in the early stages of auditory processing may be recovered by top-down processes (Rabbitt, 1968). They compared the performance of younger and older adults with respect to their ability to use contextual information. In order to do this they used the revised SPIN-R test which consists of eight lists with 50 sentences each. The task of the subject was to listen to each of the sentences in the list and to repeat the sentence-final word. In 25 of these sentences the final word was predictable from the sentence context (high-context condition) whereas in the other 25 sentences it was not (low-context condition). The sentences were presented at different noise levels. A psychometric function, which specified the percentage of correctly perceived words as a function of noise level, was calculated for each subject for the low- and high-context condition separately. The difference between the functions of the low- and high-context condition can be taken as reflecting the subject's use of context in order to recover information lost in the perceptual process. If young and old adults were equally efficient in using contextual information to recover words in noise they should show the same amount of increase of correctly repeated words from the low- to the high-context condition. For example, consider the point on the low-context psychometric function of the young adult Y3 who correctly heard and identified 20 % of the words on a certain noise level. At the same noise level, he correctly identified about 25 % of the high-context words. Thus, cognitive processes could extract compensatory information from sentence context to boost the percentage of correctly identified words by 5 %

up to 25 %. Now consider the old subject O1 identifying 20 % of the words correctly in the low-context condition. If he was as equally efficient as the young adult he should also be able to boost the percent of correctly identified words by 5 % in the high-context condition. However, if the older participant was able to make better use of the context he should show a higher increase of correctly perceived words than the younger subject. Indeed, Pichora-Fuller et. al. demonstrated that when hearing conditions were adjusted to produce an equivalent level of perceptual stress in all participants older subjects in the high context condition had a higher increase in correctly perceived words than young subjects. The older participant O1, for example, improved his performance from 20% in the low-context condition up to 50% in the high context condition, an increase of 30% due to compensatory cognitive processes. This shows that aging does not necessarily lead to a decline of cognitive abilities, on the contrary some cognitive abilities, as the use of contextual information, appear to improve with age.

Theoretical Accounts

Three major theoretical frameworks have been put forward to account for age-related cognitive decline. The first approach to be mentioned is the idea of limited mental energy or processing resources (Craik & Byrd 1982; Craik & Simon, 1980; Hasher & Zacks, 1979). Related to this approach is the notion of environmental support, and encoding specificity which will be reviewed. Moreover, studies using divided attention are to be mentioned in order to support the hypothesis of limited resources.

Following this, the mental slowing hypothesis, introduced by Salthouse (1985), and inhibitory mechanisms, that are believed to change with age, will be discussed.

Limited Processing Resources Hypothesis

The limited processes account is based on several assumptions. First, Kahneman (1973) suggested that overall cognitive resources in episodic memory might be limited by their nature. Second, it was argued that these mental resources may be even further reduced in the elderly (Cohen, 1987; Kwong See & Ryan, 1996; Hasher & Zacks, 1988; Wingfield, 1996). Third, it was proposed that mental resources may play a crucial role in governing controlled (Schneider & Shiffrin, 1977) or effortful (Hasher & Zacks, 1979; Cohen, 1987; Kwong See & Ryan, 1996; Hasher & Zacks, 1988; Wingfield, 1996) cognitive processes. The observed decline in cognitive task performance experienced by older adults is in line with those assumptions. A pronounced age-related decline of performance of older adults on certain cognitive tasks as compared to younger adults has been interpreted as showing that those tasks require a substantial amount of cognitive resources or self-initiated processing (Craik, 1986; Rabinowitz et. al., 1982) which is especially diminished in older adults. Further evidence for the limited processing account is provided by the fact that age effects on several memory tasks are reduced when the tasks are controlled for assumed differences in the amount of processing resources needed to deal with them. One way to exert control over processing resources is by introducing different degrees of environmental support to the cognitive task (Craik, 1983, 1986). The environmental support hypothesis argues that age differences should be reduced when support in the form of contextual cues is provided at encoding and retrieval. Craik and McDowd (1987) argued that age differences were smaller for recognition than for cued recall because recognition provides a greater degree of environmental support, and therefore requires less effortful processing. In another study, Craik and Rabinowitz (1985) asked young and old participants to study several lists of words under either intentional learning instructions or with the help of a semantic orienting question at each of three presentation durations (1.5, 3, and 6 s/word). They found that under standard, intentional learning instructions the magnitude of the age-related recall deficit increased with longer presentation durations. On the other hand, when a semantic orienting question was used to guide the encoding of the items on each list an equivalent benefit of longer study times was observed for both age groups. The results were interpreted as showing that older participants were less likely to carry out effective encoding operations unless processes were guided by appropriate environmental support during encoding and retrieval as in the semantic orienting question condition. This is interesting to note because it suggests that deficits in self-initiated encoding rather than possible constrains on study time may have caused the pronounced memory deficit in the elderly. I will come back to this finding in the discussion of the mental slowing hypothesis.

Hence, the limited resources approach suggests that encoding processes of younger and older adults are qualitatively rather than quantitatively different because older adults integrate needed information less well than their younger counterparts, a fact that appears to be even more pronounced with more encoding time allowed.

However, some studies showed that environmental support may sometimes not be beneficial to older adults. This seems to be especially true when the support is not very strong. The fact was interpreted as showing that older adults do not integrate unique aspects of the context with the target and do not form a distinct encoding to the same extend as younger adults because this would require a substantial amount of attentional resources which are supposedly diminished in older adults. Without having formed a distinct encoding, older adults could be at a disadvantage at retrieval as compared to younger adults. The different aspects of environmental support were illustrated in a study by Rabinowitz et. al. (1982) who asked subjects to study lists of words, a random half of the target words paired with a strongly associated cue (king-QUEEN), and the remainder paired with a weakly associated cue (whisky-WATER). At retrieval half of the target items were cued by their original stimulus words, whereas half were cued by new extralist cues that were either strong or weak associates of the target words. This meant that a target item could be tested either with the strong or weak associate it was paired with at encoding or with a new strong or weak associate. Results showed that older participants benefitted in the condition where target items were encoded and retrieved with the help of the same strong cue. Rabinowitz et al. concluded that strong cues tap general or core semantic information so that older participants can construct a stereotypical encoding of the event without exceeding the limits of the processing resources. However, when weak-associated cues are presented on the study list, it is argued that context-specific information has to be encoded if the same cue is to be successful at retrieval. The encoding of context-specific information is hypothesized to require more attentional resources and thus more effortful processing to achieve an effective integration of the novel relationship between the cue and the target. And since Rabinowitz and his colleagues assume that older adults have less attentional resources to achieve this effective integration they encode the weak pairs poorly and thus do not benefit from a reinstatement of the weak-associate cue at test.

Very similar to the environmental support hypothesis is the encoding specificity principle (Tulving & Thomson, 1973), which suggests a facilitation of recall when cues presented at encoding are also presented at test. Those cues can either be present in the environment or be self generated; in any case, they are integrated as contextual information with the target information to facilitate later recall. According to several studies (Burke & Light, 1981; Craik &

Simon, 1980; Kliegl & Lindenberger, 1993), older people may not associate the information they are trying to learn with contextual cues in the learning environment to the same extent as younger adults. Kliegl and Lindenberger, for example, found a reliable age difference in the susceptibility to intrusions and explained this by saying that older adults integrate context information to a lesser degree into their traces so that poorly learned previous, irrelevant material keeps interfering with the relevant material.

As a last source of evidence for the limited resource hypothesis, memory experiments using the divided attention paradigm are mentioned. A number of studies showed that divided attention at encoding disrupted memory performance, indicated by a decrease in word recall, to a greater extent in older adults than it did disrupt memory performance of younger adults (Park, Smith, Dudley, & Lafronza, 1989; McDowd & Craik, 1988). On the other hand, there are studies (Anderson, Craik, & Naveh-Benjamin, 1998) that did not show a differential decline in memory but a differential increase of secondary task costs for older adults. The differential decline of memory of older adults in the divided attention paradigm supports the notion that the distraction task disrupted the less elaborate organizational processes of older participants at encoding more and further impaired the ability to engage in demanding and self-initiated operations at encoding. This differential effect was assumed to be due to the more severely limited capacity of processing resources in older adults.

In summing up it can be stated that evidence from different sources and designs has been presented in order to support the notion of limited processing resources in older adults. As a consequence of this severe limitation, older participants appear to show a decline in memory performance if no environmental support, too little, or inappropriate support is provided. Their encoding processes seem to be less efficient. This, in turn, seems to make them more susceptible to intrusions. Further evidence for the limited resources view was provided by several studies examining divided attention which showed a differential decline in older participants' performance. It was also shown that divided attention during encoding can result in a similar memory performance of younger and older adults but that encoding is sometimes associated with higher secondary task costs in older than in younger adults. This increase in reaction time costs during retrieval is interpreted as showing that retrieval makes greater demands on attentional resources for older than for younger adults.

In order to draw a complete picture it has to be mentioned that an age-related decline of memory performance has not always been obtained. Several studies (Park, Puglisi, Smith, & Dudley, 1987; Puglisi, Park, Smith & Dudley, 1988) that used pictures as stimuli demonstrated that older adults benefited to the same extent as young adults from encoding specificity. In these experiments, a decline of memory performance of older adults was only observed with word stimuli under divided attention but not under full attention with word nor picture stimuli. Therefore, Puglisi et. al. (1988) reasoned that only under very difficult encoding conditions older adults may show a deficit in specific encoding.

Although there appears to be convincing evidence in favor of a limited processing resources account, there are aspects of the approach that can be questioned. An example is the direct influence that cognitive effort is assumed to have on processing resources. In their meta-analysis, Verhaeghen et. al. (1993) did not find any correlation between cognitive effort on certain tasks and processing resources. First, they expected the magnitude of the age differences in short term memory to covary with the amount of cognitive processing required. Surprisingly, this was not the case. Rather, they found that the same processes sometimes required different amount of cognitive effort depending on the material; for example, storing information about letters, words, and playing cards yielded effect sizes larger than those for storing digits. On the other hand, processes that were assumed to be different showed the same amount of cognitive effort as the Digit Span Forward and Backward yielded similar effect sizes, even though the Digit Span Backward is assumed to take up more processing resources. Second, age differences in list recall were more pronounced for shorter lists which presumably required less processing resources. These findings do not support the notion of limited processes as explained and used in this context.

As seen in the previous review, experimental evidence can be found for the following statement: Divided attention can have direct influence on memory performance. This is believed to support the notion that limited mental processing resources can directly influence memory performance. But older adults are not only characterized by the hypothesized limitation of their mental resources but also by a decline of perceptual abilities as will be discussed in the following chapter.

Both factors, decreased perceptual capabilities and reduced processing resources, are likely to interact. One way of how they may interact in the present study is to be hypothesized: Since external cues are impoverished or perceived less accurately as people age, reliance on top-down processing increases and listening becomes more effortful (Pichora-Fuller et. al., 1995). Older adults may have to allocate more of their mental energy to the perception process to disambiguate speech material with the help of top-down processing in order to perceive it faultlessly. This leads to a diversion of mental resources and increased effort. Resources which should be used for the rehearsal of the information are now reallocated to the perceptual processing. And since these working memory resources are believed to be severely limited in the elderly they now become overloaded. This may deleteriously affect linguistic and cognitive processes such as memory (Schneider, 1997; Rabbitt, 1991) because under these circumstances rehearsal can be accomplished only incompletely and fewer words may be correctly or completely encoded. This, in turn, is likely to result in a low performance on the memory task (Rabbitt, 1968).

Summing up the evidence for age-related cognitive differences related to paired-associate recall, it can be stated that older adults may not integrate novel relationships between word pairs they are trying to learn as effectively as younger adults (Rabinowitz et. al., 1982) and thus they may not profit from the reinstatement of the same cues to the same extent. This failure is especially marked when older adults are asked to form associations between weakly related events (also see Light & Burke, 1988; Hess, 1990; Hess, Donley, & Vandermaas, 1989). Thus, encoding efficiency appears to be less affected by age for strongly related information where context plays a role. For unrelated information, however, the age difference seems to be considerable. This phenomenon is likely to be a qualitative change in adult age memory. Furthermore, it has to be mentioned that the age differences just described have not been invariantly obtained (Puglisi et. al., 1988, Park et. al., 1987) so that their robustness is questionable.

Age-related Slowing Hypothesis

A second approach, the age-related slowing hypothesis, has been proposed by Salthouse (1985). It suggests that the age-related cognitive decline is a result of a reduction in speed at which older adults can execute many elementary processing operations in their cognitive system. It follows that age differences can only be minimized when there is a well-specified criterion that older adults had been unable to meet primarily due to time limitations. It remains a matter of discussion how much processing speed contributes to the relation between age and various measures of cognitive performance. It seems that the influence of speed on a cognitive task varies with the nature of the speed measure. Salthouse (1993) suggests that it is generally greatest with measures that have cognitive components and least with measures that primarily involve sensory and motor aspects. The general finding is a reduction in speed with which older adults can accomplish many cognitive tasks. Further support for a direct relation between processing speed and cognitive performance was added by Kliegl & Lindenberger (1993). They used a rather unusual design in which age-related differences in memory performance were not, as usual, reflected in accuracy of recall expressed by the number of words correctly recalled but in the amount of encoding time needed to recall a certain number if words specified a priori. Usually, presentation time for both young and older adults is fixed and differences in the number of words recalled in some sort of memory test is interpreted as showing differences in the speed with which the stimuli can be processed and integrated for later recall. In this study, however, the number of words that had to be recalled was fixed at 50% and the study time needed to achieve the criterion was adjusted. The results of the study showed that providing longer study time at encoding significantly reduced age differences on the amount of verbal material recalled. Hence, both younger and older adults were able to meet the 50% recall criterion. Age-related differences were now displayed in the amount of time study time needed in order to achieve the criterion. Thus, this result supported the general cognitive slowing hypothesis of elementary cognitive processes.

Although results from many studies suggest that the poorer memory performance of older adults is a direct consequence of the reduction in speed at which older adults can execute many elementary cognitive processes, and providing more time can minimize this deficit, in situations involving more complex problems and higher order cognitive functions, providing more time can result in younger adults speeded cognitive operations maximizing rather than minimizing age-differences (Park, 1992). This can lead to results contrary to the predictions derived from the mental slowing hypothesis. Evidence for this mechanism was provided by Craik and Rabinowitz (1985) who tested younger and older participants on a free recall and a recognition test given three different presentation time intervals (1.5, 3, and 6 s/word) at encoding. In free recall, largest age differences were found for the intentional learning condition at the slowest presentation rate. Craik and Rabinowitz argued that provision of more time to carry out self-initiated encoding and rehearsal activities was more beneficial to the younger subjects. This finding is directly contrary to the prediction derived from the mental slowing position.

As opposed to the notion of limited processing resources, the general slowing hypothesis suggests that the difference between cognitive performance of younger and older adults is only quantitative in nature. Correlational studies using regression analysis on a wide range of tasks and speed as a dependent variable (Cerella, 1990; Cerella, Poon, & Williams, 1980; Hale, Myerson, & Wagstaff, 1987) supported this idea by showing that mean speed of older participants can be well predicted from knowing the mean speed of younger adults on the same task; no additional information about processes involved or the exact nature of the task are required (Verhaeghen & Marcoen, 1993). Thus, many correlational studies revealed speed as a mediator of adult age differences in memory (Salthouse, 1996; Hultsch, Hertzog & Dixon, 1990). In these studies controlling for processing speed substantially reduces age-related variance in memory measures. Park, Smith, Lautenschlager, Earles, Frieske, Zwahr, and Gaines

(1996) obtained a complete elimination of age differences in a cued recall task after statistically controlling for speed. In a study conducted by Sliwinski and Buschke (1997) age-related variance in three of four memory measures was attenuated by at least 95% by statistically controlling for processing speed. In the fourth task, variance in memory performance was reduced by 90% after controlling for speed.

These results suggest that there is little evidence for differences in specific age-related memory processes as encoding and retrieval since age-related decline is substantially reduced by statistically controlling for processing speed. Instead, the decline in memory functioning may result from a more general deficit in processing speed (Sliwinski & Buschke, 1997). Salthouse (1994) suggested that some of the encoding difficulty in an associative learning task very similar to the one used in this study may have been related to a slower speed of processing. This reduced speed may have reduced the amount of elaboration needed to integrate the two words within the available time.

Although many results in favor of the general slowing hypothesis have been presented, this quantitative approach is not completely convincing since in some correlational studies, even after controlling for speed, residual age differences remained that had to be accounted for (Nettelbeck & Rabbitt, 1992; Salthouse, 1994; Salthouse, 1996). Those residual effects might point to specific memory processes that need to be accounted for by an explanation not involving speed. Hypotheses about the nature of those specific memory processes were introduced within the framework of the limited processing resources account.

Summing up the results, it can be said that the general slowing approach emphasizes the quantitative component in the relationship between the cognitive performance of younger and older adults. According to this approach, aging is associated with an overall slowing of elementary cognitive processes. This slowing, in turn, results in apparent difficulties in cognition. No further specific age-related changes are assumed.

Inhibitory Mechanisms and Aging

A third theoretical framework suggests dysfunctional inhibitory mechanisms as a reason for the decline in cognitive performance (Hasher & Zacks, 1988). The proposed dysfunctional inhibitory mechanisms may be one reason for the results found by Murphy et. al. (2000). In their study, younger and older subjects were individually adjusted for background babble in order to make it equally difficult for them to hear individual words. Even though the perceptual stress was the same for both age groups younger adults outperformed older adults on all serial positions in a paired-associates memory task. The results of Murphy et. al. could be due to the older listeners inadvertently trying to process the babble. This does not mean that younger adults do not engage in this process but that older adults do it to a greater extent. There is further evidence supporting this notion in studies conducted by Anderson et. al. (1998) who showed that older adults were less able to exercise conscious attentional control over their encoding processes. In other words, older adults have difficulty in focusing their attention and preventing the processing of irrelevant material. They seem to have weaker inhibitory mechanisms so that task-irrelevant information makes its way to the working memory. The irrelevant information then gets high activation and takes up mental resources that could have been used to process the task-relevant information (Anderson & Craik, 1974).

Three influential theories were introduced in order to account for older adults□ decline in the performance of cognitive tasks. Whereas the limited processing resources account suggests qualitative changes in cognitive mechanisms, the general slowing hypothesis assumes only quantitative differences in cognitive processing of younger as opposed to older adults. The dysfunctional inhibitory processes account assumes that the cognitive decline of older adults is due to weaker inhibitory mechanisms which result in the processing of more irrelevant material. One of the purposes of the present study was to attempt to determine if age-related differences in the ability to inhibit the processing of background babble contributes to the age-related differences in the paired-associate memory task embedded in babble.

Perception

There are age-related changes in the peripheral auditory system which could lead to a decreased ability to hear individual words in difficult listening situations (i.e., when there is distortion or background noise). Among these changes are a reduction of spectral and temporal resolution (Schneider, 1997; Dreschler & Plomp, 1985; Ginzel, Pedersen, Spliid, & Andersen, 1982), a decreased sensitivity, especially in high frequencies (Humes, Watson, Christensen, Cokely, Halling, & Lee, 1994; Wingfield, 1996) and a higher vulnerability to the presence of background noise (Dubno, Dirks, & Morgan, 1984; Duquesnoy, 1983; Gordon-Salant, 1986).

The loss in temporal resolution of the perceived stimulus is now discussed in more detail. A loss of temporal resolution manifests itself, among other things, in a larger gap detection threshold which can be found in most listeners with hearing loss (Buus & Florentine, 1985; Glasberg & Moore, 1989; Moore & Glasberg, 1988). However, it appears that peripheral hearing loss and loss of temporal resolution are not highly correlated. Several studies (Moore, Peters, & Glasberg, 1992, Schneider, Pichora-Fuller, Kowalchuk, & Lamb, 1994; Strouse, Ashmead, Ohde, & Grantham, 1998) attempted to control for the confounding effect of age-related hearing loss on gap detection thresholds and found that older listeners with near-normal hearing nevertheless had higher gap detection thresholds than their younger counterparts. Studies even showed that when comparing older adults with near normal hearing and older adults with hearing loss, no differences in gap detection thresholds could be found (Schneider et. al., 1994; Snell, 1997). Recent research results appear to show that there is an absence of correlation between hearing loss and a loss of temporal resolution not only for the older age-group but that gap detection thresholds are not significantly correlated with audiometric thresholds in either age group (Snell & Frisina, 2000). In the next section the nature and possible manipulations of temporal resolution are discussed.

The Nature of Temporal Resolution

An auditory signal can be decomposed into a sum of sinusoidal signals varying in amplitude, frequency, and phase. Since all the information of the signal is contained in the sum of those sinusoidals, anything that disrupts or distorts any one of the sinusoidal components will affect the information contained in the signal. Random jitter is one of the possible distortions in the transmission line. It is a time based error in the transfer of information. It can be observed when information is converted from a continuous into a discrete form. Jitter can change the original information. It can be a potential source of error for all discrete information that is coded with the help of time. Human hearing is one example where part of the information is coded temporally. Therefore, a time based error in form of a delay can be introduced into the transmission line. Where a delay becomes variable in the auditory nervous system, it can disrupt or distort the information contained in the signal.

Jitter is not a new phenomenon but has already been investigated mainly in connection with digital signal processing and communication devices (Takasaki, 1991). Moreover, audiologists have stated that time based information might be an important part of signal processing in hearing that helps to perceive tones as a whole, tone pitches, the location of a tone and so on (Moore, 1989; Pickles, 1988). When temporal information is degraded, the accuracy with which tones, tone pitches, and the location of a tone can be perceived declines (Moore, 1998). Consequently, a loss of hearing and understanding spoken words can be observed in many cases where temporal information is believed to be internally jittered and thus degraded. Aging could be one of those factors that lead to an increased amount of the internal jitter which, in turn, degrades temporal information and subsequently leads to hearing loss. Jitter can be generated externally in technical devices or internally in the human nervous system. In the following, both mechanisms will be described. It seems advantageous to draw the analogy to digital signal processing and the way digital processing in technical devices works, in order to understand the functioning of jitter in the auditory domain. Moreover, it is assumed that jittering stimuli externally mimics the internal jitter process. External jitter will be described first.

External Jitter.

A signal, whether a pure tone or a speech signal, consists of a waveform. Every signal produced by a living being has an analog form. In order to enable a digital device to analyze a signal it has to be converted into a digital form. The analog to digital conversion process involves two steps: First, the analog signal has to be sampled at a certain frequency (Saito &

Nakata, 1985). Second, the measured voltage value of every sample is converted into a number which represents the amplitude. The numerical value of the number does not have to be identical to the voltage value, it only has to be proportional. For the understanding of jitter the sampling process itself is important and will therefore be investigated. In order to convert an analog to a digital signal a number of discrete samples have to be drawn from the continuous analog signal. This changes the signal function from an indefinite collection of real numbers into a finite collection of integer numbers. It is important to represent the infinite number of possible values of the signal in a finite number of integer values equally well for all parts of the signal. Therefore the sampling process has to be well balanced. This balance is achieved by a pulse generator in the sampling device which creates an ideal time raster by allocating equally spaced time slots for all parts of the signal to be sampled. Hence, the time between sampled parts is exactly set. In an ideal sampling process the samples of the signal would exactly fit into these time slots. Unfortunately, the intended equally spaced time slots and the actual sampling times are not necessarily identical. The variation between the intended time slots and the actual sampling times leads to a change of the digitized signal in comparison to the original signal. This variation distorts the signal temporally (temporal jitter).

Since the time slots are equally spaced the arrival times of the signal should be integer multiples of this raster. The actual arrival times of the signal can deviate from this pattern. The distortion can be systematic or at random. Takasaki (1991) suggested several schemas to classify time based distortion (jitter). They include a classification by time reference, jitter source, jitter characteristics, and digital sequence. The only characteristic that is examined here is the classification by jitter characteristics. The main difference between jitter in this respect is whether jitter occurs in a systematic pattern or at random. Figures 1 and 2 give examples for both kinds of jitter. In Figure 1 the actual arrival times of the signal are randomly varied over

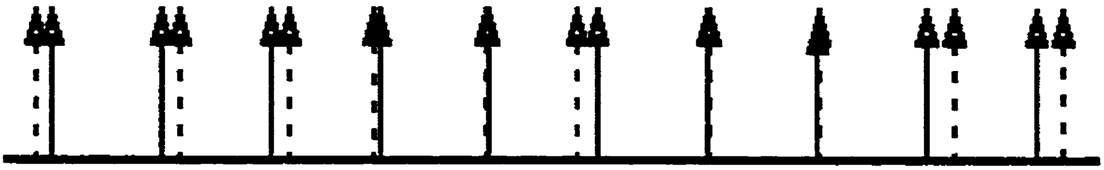

Figure 1. The occurrence of random jitter in digital devices. The actual arrival times of the samples of the signal deviate at random from the allocated time slots in which they should fit.

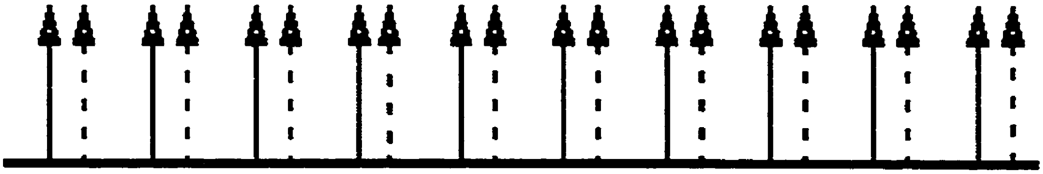

Figure 2. The occurence of periodic jitter in digital devices. The arrival times of the samples of the signal deviate periodically from the allocated time slots. They are multiple integers of the ideal time raster.

the ideal time slots and occur before and after the slots with the same probability. In Figure 2 the arrival times have a systematic pattern and are removed from the ideal time slot by the same amount of time for every sample. As the sampling rate increases a higher amount of jitter occurs.

In order to quantify the amount of jitter the standard deviation of the time, the actual arrival of the digitized sample deviates from the ideal time slot, is computed for each sample. The equation for this procedure can be seen below. **x** symbolizes the time pattern of the ideal time slots whereas $\mathbf{x_i}$ represents the actual arrival times of the samples. When the actual arrival times of the signal are randomly varied over the ideal time slots, the difference in the brackets can be either positive or negative (the mean delay being zero) depending on the fact whether the actual sample arrives before or after the occurrence of the allocated time slot. All differences are squared, the squared values are summed up, averaged, and the square root of the value is taken (Moore, 1998). The outcome of this procedure is widely known as RMS value. Jitter analysis based on the RMS criterion is convenient for evaluating the quality of the received signal.

$$\sqrt{\frac{\Sigma\left(x_i - \bar{x}\right)^2}{n}}$$

Internal jitter

In order to extract the information inherent to the auditory stimulus at a higher processing level the human nervous system has to unequivocally encode the stimulus. In order to encode information about a stimulus the nervous system uses frequency coding. Frequency coding is achieved by neurons firing at certain frequencies which results in characteristic interspike intervals. Among other information of an auditory stimulus the frequency of a tone is encoded by interspike intervals. The time between spikes in the auditory neurons is an integral multiple of the period of the stimulus. This means that a given neuron does not necessarily fire on every cycle of the stimulus' waveform but, when firings occur, they occur at roughly the same phase of the waveform each time. This phenomenon is referred to as "phase-locking" (Moore, 1989; Pickles, 1988). The auditory nervous system of younger adults is characterized by a high degree of phase-locking which means that the frequency of the stimulus and the frequency of the neural firings are highly synchronized for frequencies up to 6000 Hz. For example, in a 1000 Hz tone each sinusoid needs 1 ms to complete one period, so that the period is 1ms. Thus, the interspike intervals between the nerve firings might be 1 ms, 2 ms, 3 ms, or 4 ms, etc. To illustrate this, Figure 3 shows a sinusoidal 1000 Hz tone. Neural impulses are separated by multiples of approximately 1 ms so that the 1000 Hz tone is encoded by a neuron's firing frequency of 1000 Hz.

Schneider (1997) has postulated that there is a loss in phase-locking in older adults. As stated before, each neural firing frequency presents exactly one tone frequency. Aging is assumed to alter neural firing. The neural impulses do not occur exactly at integral multiples of the stimulating tone anymore at frequencies much lower than 6000 Hz. The interspike intervals become variable and the neural response asynchronous. Figure 4 shows the same sinusoidal 1000 Hz tone but now the neural responses are asynchronous. Thus, more frequencies are encoded than the one originally presented. This phenomenon is referred to as "internal jitter", a spectral splatter that occurs and is centered on the original tones' frequency. These findings

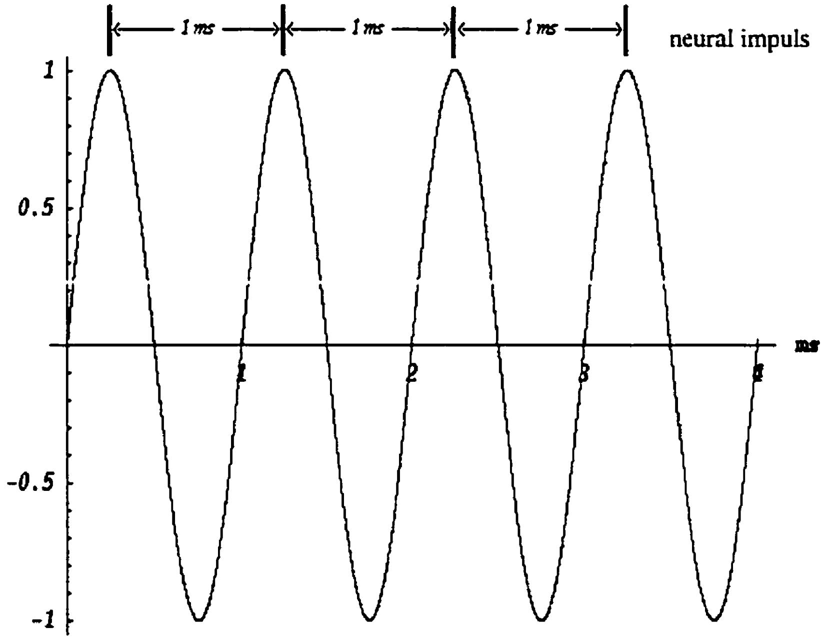

Figure 3. The auditory nervous system of younger adults is characterized by a high degree of phase-locking. Neurons fire in fixed time intervals, here the neural firing is triggered at the positive peak of the sinusoid.

suggest that an age-related loss in temporal resolution may degrade the speech signal and makes it more difficult to process the rapid fluctuations in amplitude that are characteristic of normal speech (Schneider, 1997). This could be a major contributing factor to the speech understanding difficulties that older adults usually experience. In line with this research are findings that have linked reduced temporal processing to some speech perception errors made by hearing-impaired listeners (Price & Simon, 1984; Tyler, Summerfield, Wood, & Fernandes, 1982). As shown

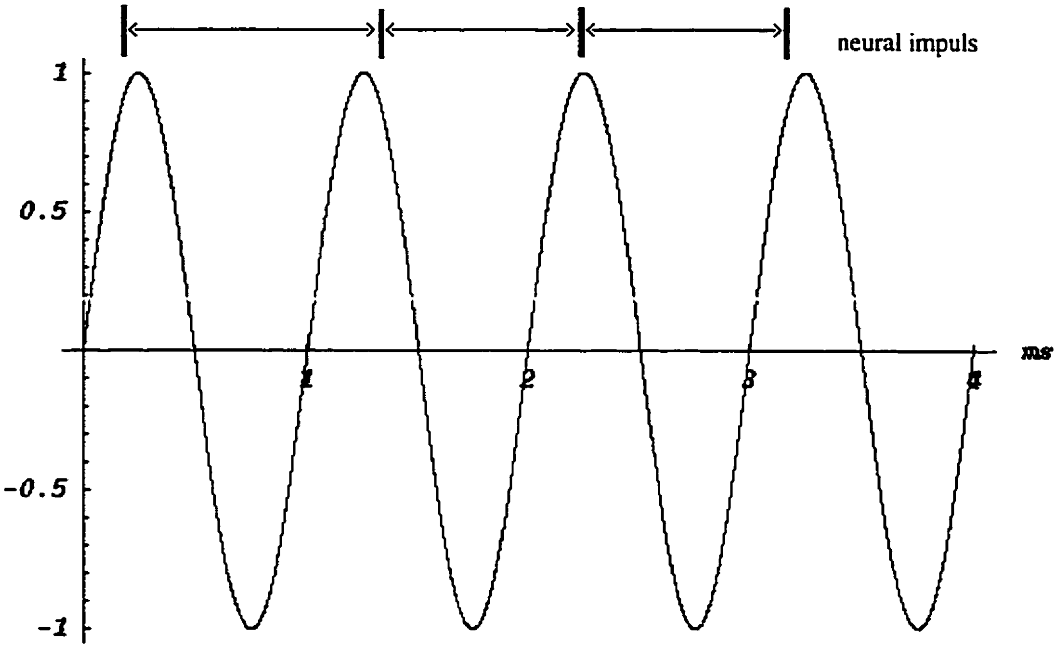

Figure 4. The auditory neuron of the nervous system of older adults is characterized by a loss of phase-locking in frequency coding. The neural impulses vary and do not occur exactly every 1 ms.

above, an association between reduced temporal processing abilities and speech understanding in noise for older adults has been shown to be independent of the presence of sensorineural hearing loss. This was interpreted as explaining why older adults with good audiograms nevertheless can find it difficult to understand speech, especially when the environment becomes noisier and the speech more rapid (Bergman, 1980; Duquesnoy, 1983; Schneider, 1997).

It has to be mentioned that there is no complete consensus about the fact that temporal processing ability, measured by gap detection thresholds, is important for an accurate perception of speech. Some multivariate correlational analyses found a significant correlation between gap detection and speech recognition ability even after audiometric threshold was factored out. In those studies a reduced gap detection ability was associated with a poorer performance on speech in noise tests (Dreschler & Plomp, 1985; Tyler et. al., 1982). Other studies did not find significant correlations between the factors (Divenyi & Haupt, 1997; Festen & Plomp, 1983; Van Rooij & Plomp, 1990). Thus, temporal processing measures have not consistently proven to be strong predictors of speech perception. There are at least three possible explanations for this finding. One explanation is the fact that the mechanisms underlying the detection of temporal gaps may be different from mechanisms underlying the ability to distinguish temporal characteristics of speech. Hence, the perception of speech sounds would be fundamentally different from that of non speech stimuli (Strouse et. al., 1998). Second, it is possible that only measures of more complex temporal processes provide good predictors of speech performance. Evidence for this was provided by Gordon-Salant and Fitzgibbons (1997) who derived a formula by discriminant function analysis that effectively distinguished the performance patterns of younger and older listeners in speech and non speech measures. The most important measures to accomplish this goal involved conditions featuring temporal manipulations of complex speech and non-speech signals. Third, it is possible that age-related changes in temporal acuity may begin decades earlier than age-related changes in word recognition (Snell & Frisina, 2000) so that a correlation between the measures may only be found in an advanced stage of temporal distortion of the auditory system.

To sum up the research results, there are several perceptual factors that account for age-related differences in the processing of auditory stimuli. Peripheral hearing loss and a loss of temporal resolution with age have widely been found. This was also supported by Humes and

Christopherson (1991) who demonstrated that the perceptual input is poorer for older adults. In their study they found no difference between masker-simulated hearing loss in younger and sensorineural hearing loss in older listeners in a speech identification task. Hence, researchers conducting similar studies concluded that older adults simply have difficulties hearing speech cues (Ryan, Giles, Barolucci, & Henwood, 1986; Rabbitt, 1991, 1968), which may result in a degraded or less stable mental representation of the stimuli in memory (Pichora-Fuller et. al., 1995). A common conclusion is that speech recognition difficulties of older adults are primarily a consequence of hearing loss. (Humes & Christopherson, 1991; Nabelek, 1988; Van Rooij & Plomp, 1990, 1992; Humes, 1996; Humes, Watson, Christensen, Cokely, Halling, & Lee, 1994). The observed hearing loss may be due to a reduction of spectral and temporal resolution (Schneider, 1997), a decreased sensitivity (Humes et. al., 1994; Wingfield, 1996), a higher vulnerability to background noise (Dubno et. al., 1984; Duquesnoy, 1983; Gordon-Salant, 1986), or to any combination of those factors.

However, perceptual decline does not seem to be the entire story. There are also impairments in the cognitive processing of the material as indicated by a number of studies where the variance in speech understanding did not appear to be completely accounted for by such hearing measures as pure tone thresholds (Dubno, Dirks, & Morgan, 1984; Helfer & Huntley, 1991, Helfer & Wilber, 1990; Bergman, 1980; Duquesnoy, 1983; Schneider, 1997). This was especially true for listeners 75 years of age and over who performed significantly worse than a group of young-old (65-75 years of age) listeners with similar audiometric thresholds in the study by Humes and Christopherson (1991). Very similar results were obtained by Gordon-Salant and Fitzgibbons (1997). In their study, young normal-hearing adults showed the highest performance on sentence recall, older adults normal-hearing adults showed a somewhat reduced performance, and the poorest recall performance was shown by older adults with hearing loss. The results were interpreted as showing the overall effect of aging in the comparison between recall of young and older normal-hearing adults and moreover a differential effect of hearing loss in the comparison between older normal-hearing adults and older adults with hearing loss. In another study (Hargus & Gordon-Salant, 1995) young normal hearing listeners□ threshold was elevated by noise-masking to fit that of elderly listeners with hearing impairment. Although audibility of the stimuli were equated, elderly listeners performed significantly worse than young listeners in speech intelligibility across a range of test conditions and stimuli. The results were interpreted as suggesting that speech recognition difficulties did not result solely from reduced auditory sensitivity. It appears that although older adults can use top-down processing to recover part or all of the information lost in the perception process (Rabbitt, 1968) this leads to a decrease in processing resources (Schneider, 1997; Rabbitt, 1991) which may already be limited. The link between age-related limitations in processing resources, decreased auditory functioning, and speech understanding among older adults was nicely demonstrated by Pichora-Fuller et.al. (1995). In their study, they used high and low context sentences from the revised speech perception in noise (SPIN-R) test embedded in babble in order to estimate psychometric functions of younger normal-hearing, older normal-hearing, and older presbycusics listeners for identifying the sentence final word. In a second step they added a working memory task in which subjects were asked not only to identify final words but also to keep them in mind and recall them when asked to do so. Although equated for the number of items perceived, elderly listeners recalled fewer of the items they had perceived than did younger listeners. The results were interpreted as supporting a processing model in which reallocable processing resources are used to support auditory processing when listening becomes difficult either because of noise, or because of age-related deterioration in the auditory system. Because of this reallocation, the resources are unavailable to more central cognitive processes such as encoding. Thus, auditory deficits appear to exert influence on cognitive performance directly by distorting the auditory input and indirectly by using up processing resources needed to execute cognitive processes.

The Manipulation of Temporal Resolution

The experiments to be reported were designed to explore the effects of age on perception and cognition, and their possible interactions. Specifically, the experiments were constructed to explore the extent to which age-related deficits in perceptual (temporal) processing and deficits in cognitive performance, especially in focused attention and processing resources, account for age-related differences in performance of a paired-associates memory task.

In order to examine the hypothesis that internal jitter is one of the reasons why older adults perform more poorly in understanding spoken words in noise than do younger adults, one has to find a way to mimic the temporal asynchrony. This can be accomplished by externally "jittering" the stimulus presented to younger adults. To simulate the effect of different extents of internal jitter, the stimuli were jittered by modulating various external temporal delays of 6, 7, 8, 9, or 10 standard deviations with a low-pass noise of 100 Hz, the mean delay being zero seconds. Since the presented material is digitized the standard deviation is the number of samples by which a specific sound is displaced. For instance, in a condition with a standard deviation of 10 the digitized sound samples are displaced by an average of 10 sample points. The bandwidth defines the speed with which the material is jittered. The higher the bandwidth the more difficult it is to understand the word. A very high bandwidth, for example 5000Hz, leads to a mere noise signal. The result of this manipulation is to obscure or distort the temporal features of the signal and simulate the kind of auditory deficit that is believed to occur in older adults.

Figures 5 and 6 show the process of jittering. Figure 5 represents a digitized sinusoidal tone of 1000 Hz. Since there are 20,000 samples per second drawn from the continuous signal, the sampling rate of the digitized sound sample is 20,000 Hz. In Figure 6 this digitized 1000 Hz tone is jittered. Randomly selected sampling points are randomly displaced by one or two sampling points. The signal is still recognizable but the jitter has already led to some distortion. This distortion will increase when more sampling points are displaced in a shorter period of time.

Figure 7 and 8 show the spectral representation of the word “algae”. Figure 7 shows the distribution of energy as it occurs in the unjittered, naturally spoken word. Most of the energy necessary to produce the word is distributed over a small range of frequencies. In Figure 8 the word is jittered. Again, peaks occur at frequencies that are essential to present the word. But in addition to these peaks there is also energy splattered over many more frequencies. Furthermore, the energetic differences between the word frequencies and the frequencies introduced by jitter are diminished which makes it even more difficult to understand the word.

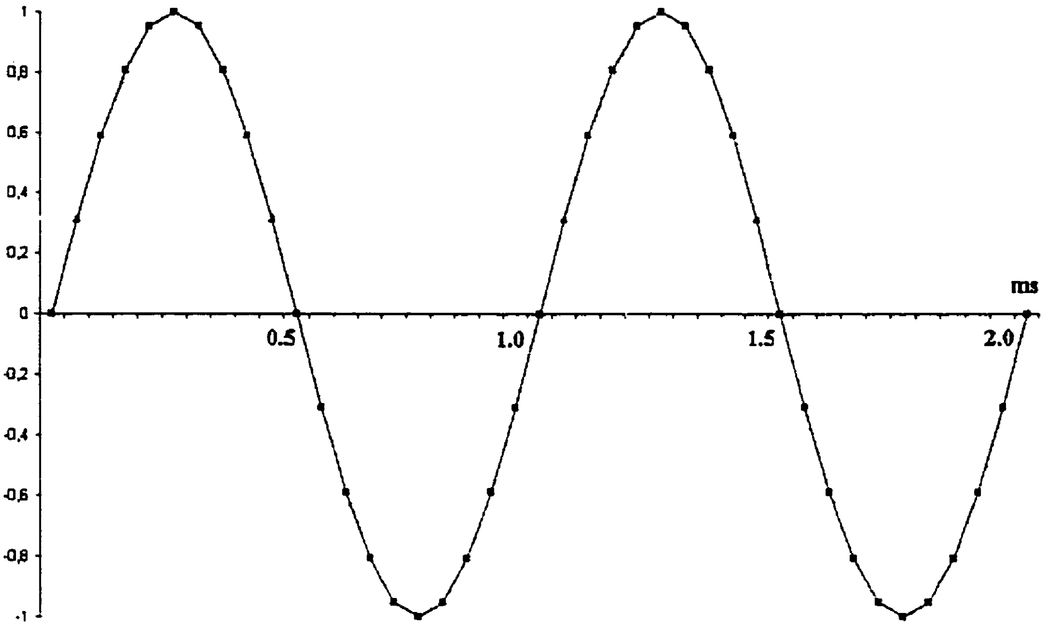

Figure 5. A sinusoidal 1000 Hz tone is digitized on a sampling rate of 20000 Hz. The dots mark the sound samples drawn from the continuous tone.

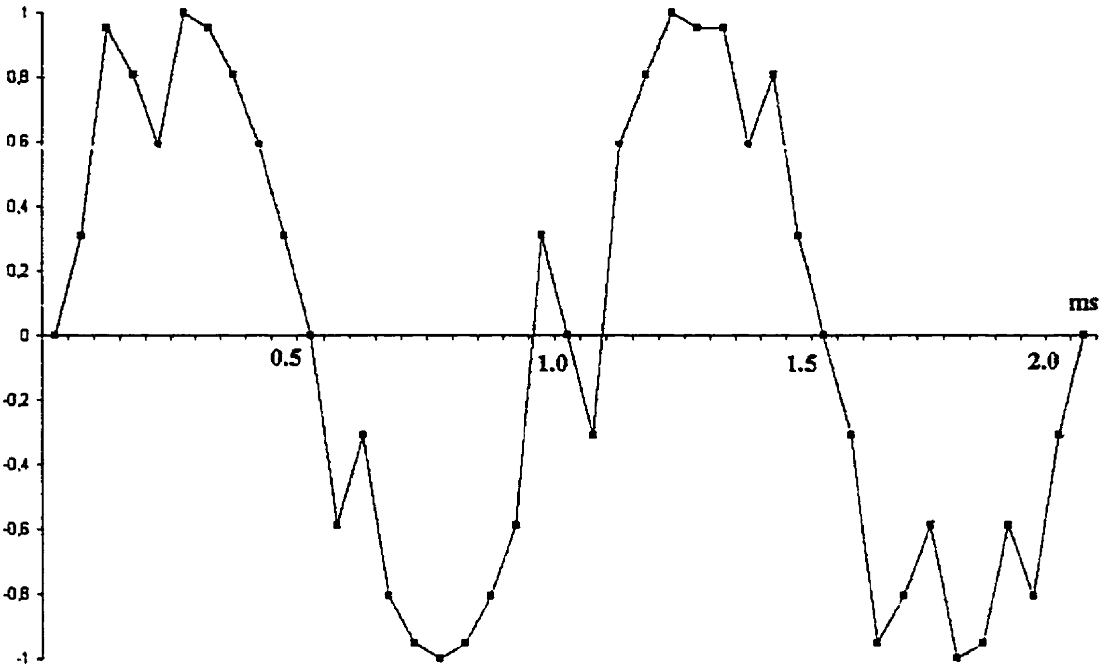

Figure 6. The digitized sinusoidal 1000 Hz tone is jittered by displacing several sampling points. Using this technique, distortion can be introduced to a digitized sound.

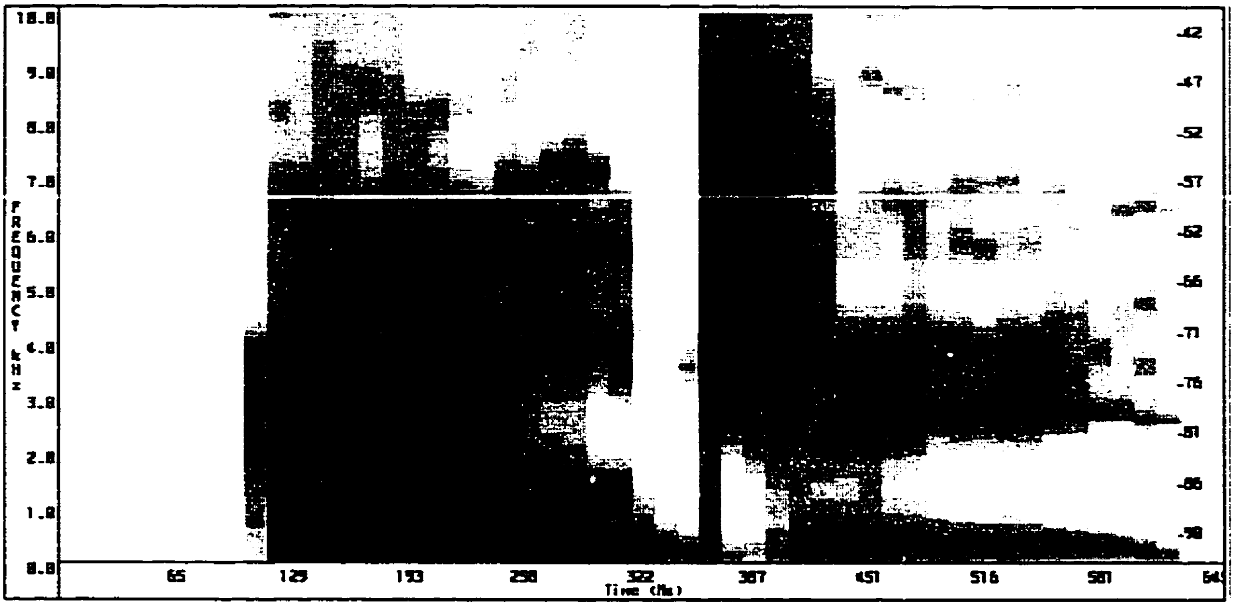

Figure 7. Spectral distribution of the unjittered spoken word "algae". The distribution of the energy over all frequencies from 1 to 10,000 Hz is expressed by different shades of gray whereas darker shades stand for higher energy. Energy peaks (dark shades) occur only at frequencies essential to represent the word.

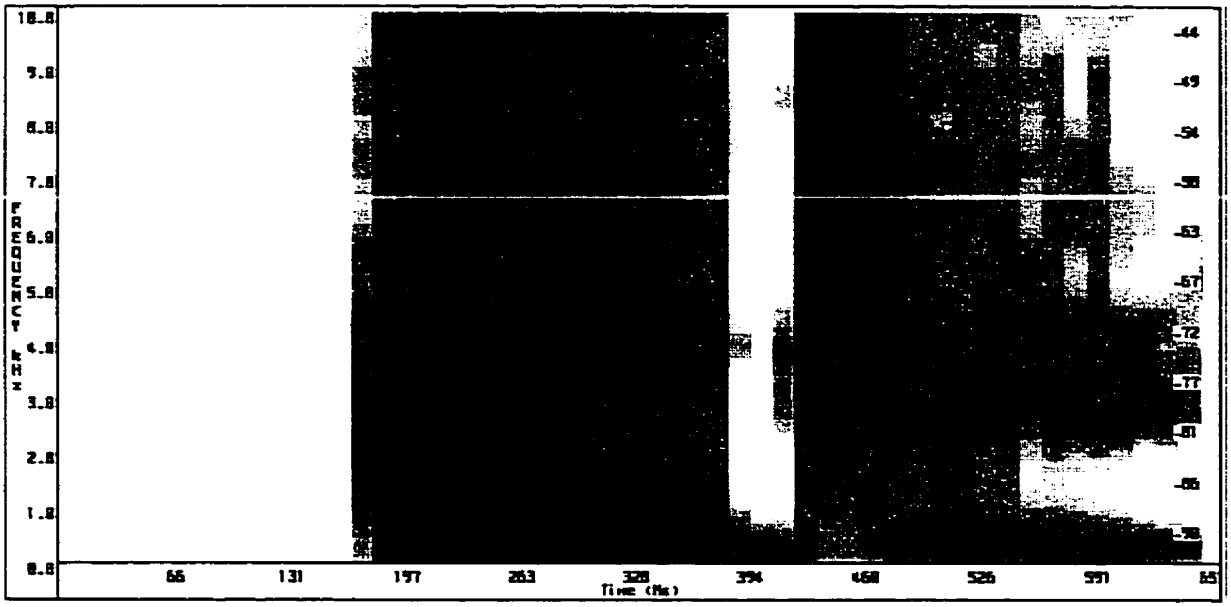

Figure 8. Spectral distribution of the temporally jittered word "algae". The word is temporally distorted with a RMS jitter of 10 and a Bandwidth of 100 Hz. As indicated by the deeper shades of the gray color considerable amounts of energy splatters over almost all frequencies.

Hypotheses

The experiments were based on the study by Murphy et. al. (2000). This study was conceptually replicated but the speech material was distorted by jitter rather than masked by background noise.

Murphy et. al. conducted several experiments in which they presented lists of five word pairs to their subjects to memorize. After the presentation of each list, participants were cued with the first word from one of the five previously presented word pairs and were required to recall the second word of the pair. Murphy and his colleagues individually adjusted the noise level to make it equally difficult for all participants to hear individual words. However, this did not eliminate age differences in memory. Even when younger adults were stressed with higher levels of noise which should have made it more difficult for them to perceive and remember the stimulus they outperformed older adults on all serial positions. Note that similar results were found using white noise instead of background babble (Kester). In her study, Kester also used a paired-associate memory paradigm, but masked the word pairs presented with white noise instead of babble. She compared her findings to the results of Murphy et. al. and showed that white noise behaved similarly to babble, and that both noise conditions had a different effect on performance of both age groups than the quiet condition.

One hypothesis concerning these results is that older adults could not inhibit processing the background babble as well as younger adults. In other words, the experiment contained an unintended divided attention condition concerning words versus babble especially for older adults so that older participants allocated a considerable amount of their cognitive resources to attempting to inhibit the background noise. These attentional deficits could be responsible for the remaining age difference.

The other possibility is that older and younger adults did not differ with respect to attending to the background babble, but that older participants had fewer resources available to perform the memory task because they allocated a higher amount of their resources to the perception of the words. Whereas for younger adults the pattern of resource allocation towards the perceptual process did not differ depending on the fact whether words had to be identified in quiet or babble, there was a reallocation of resources towards the perceptual processes for older adults as the perception of the words became harder. Hence, the already limited processing resources of older adults were further differentially diminished. Given this hypothesis and the assumption that this mechanism does not only work when perception is stressed by masking but also when perception is temporally distorted, it should not matter how the speech material is distorted so long as the distortion or masking reduces accuracy of identification by the same amount.

To test these hypotheses the presented material was distorted by jitter rather than masked by background noise. Jitter is another way of degrading words and lowering their identification rate. The advantage of using this method was that there is no attentional shift possible because there are no other meaningful words or sounds to process since jitter is not a masker. If an attentional deficit is responsible for the age-related decline in performance found by Murphy et. al. then both, younger and especially older adults, should perform better on the memory task in this experiment since their resources are not divided anymore. If the pool of processing resources is smaller in older adults than in younger adults, and if disambiguating words requires the same reallocation of resources when words are masked by babble as when they are distorted by temporal jitter, then the results should replicate those of Murphy et. al.

Experiment 1

The purpose of Experiment 1 was to find the jitter level that provided a 91% accuracy in word identification. This was necessary in order to compare the Murphy el. al. study to the present study since both studies would then be based on the same perceptual accuracy level of the words. The jitter level was determined separately for younger and older adults.

Method

Participants

Ten young[1] (mean age = 21.50 years, S.D. = 1.90) and ten old (mean age = 72.60 years, S.D. = 5.76) adults participated in the experiment. The young subjects were one male and nine female Erindale College undergraduate students whose ages ranged from 19 to 24 years. The older participants were two male and eight female community dwelling citizens, their ages ranged from 67 to 84 years of age. In exchange for their participation subjects received payment ($10/hour). Younger (mean number = 15.90 years, S.D. = 2.23) and older (mean number = 15.80 years, S.D. = 2.39) adults did not differ significantly in years of education. The Mill Hill Synonym Vocabulary Test was admistered to all but one young subject. The older subjects (mean = 15.60, S.D. = 2.76) had a slightly higher vocabulary score than the younger subjects (mean = 13.56, S.D. = 1.94). However, this difference did not reach significance ($p > .05$).

Material and Design

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[1] One participant was excluded from the study because he had almost fallen asleep during the experiment so that he had not been able to concentrate on the task. An additional participant was tested in his place.

Digitized words served as stimuli in the study. These were the same words as the ones used by Murphy et. al. (2000) in their study. To record the words, a female speaker was located within a single walled sound attenuating chamber. She spoke into a microphone that was located approximately 6 inches from her mouth. The words used consisted of two-syllable common nouns with a frequency of more than 1 per million words according to the Kucera and Francis (1967) norms. The words were digitized using the Computerized Speech Research Environment (CSRE) software at a sampling rate of 20 kHz. They were delivered through a 16-bit digital-to-analog converter (TDT DD1) followed by a 10-kHz low-pass filter (TDT FT6-2, 60 dB attentuation at 11.5 kHz), a programmable attenuator (TDT PA4), and a weighted signal mixer (TDT SM3).

The experiment was designed with age as a between-subject factor, the different levels of distortion of the words served as a within-subject variable. The words were randomly sorted into 10 lists, each list containing 40 words. Five different jitter levels (6, 7, 8, 9, and 10) were used to distort perception. Each jitter level was characterized by a modulating random external temporal delay of 6, 7, 8, 9, or 10 standard deviations and a bandwidth of 100 Hz. Each subject listened to all lists and all jitter levels. However, different combinations of list number and jitter level were used for each participant to avoid possible interactions between lists and jitter levels. Moreover, the order of list presentation was randomized for all participants. Thus, whereas list number 10 might be presented with a jitter level of 10 for one subject, the same list might be paired with a different jitter level for another subject. Note that two word lists per jitter level and participant were tested so that identification scores of 20 word lists per jitter level and age group were collected. To sum up, each subject completed 400 trials (ten lists with 40 words each) and ten subjects were tested per age group. Hence, in order to estimate the accuracy of word identification for each jitter level 800 trials (two word lists with 40 words each per jitter level presented to ten subjects) per age group were collected.

Procedures

Preceding participation in the experiment, pure-tone air-conduction and babble thresholds were determined for each subject. Moreover, all participants were asked to complete the Mill Hill Synonym Vocabulary Test, a twenty questions forced choice vocabulary test. The test took approximately 5 minutes to complete.

Audiometric Testing. The pure-tone air-conduction threshold was determined at nine frequencies (0.25 - 8.00 kHz) for both ears, beginning with the right ear. A main reason for collecting data on the right ear, although stimuli in all experiments were only presented to the left ear, was to provide participants with an opportunity to get acquainted to the equipment and procedures used in the testing procedure. An Interacoustics Model AC5 audiometer was used. All participants were required to have normal audiograms which equaled a pure-tone air-conduction threshold of less than or equal to 25 dB HL (ANSI, 1989) at 0.25 up to 3.00 kHz in both ears. Although all participants met the criteria, the group of young listeners had significantly lower thresholds than older adults for all but one (250 Hz) test frequencies in the left ($ps < .012$ or less) ear and for all frequencies in the right ($ps < .005$ or less) ear. This effect was even more pronounced at frequencies above 3000 Hz.

Babble Threshold. The babble threshold was measured to determine the ability of each participant to detect speech sounds. To accomplish this, a recording of a twelve talker babble, taken from the modified Speech Perception in Noise (SPIN) test (Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984) was used. The babble was digitized at a rate of 20 kHz using a 16-bit

Tucker Davis (DD1) analog-to-digital converter. To determine the detection threshold for the babble an adaptive two-interval forced choice procedure was used in which a babble segment was presented in one of two randomly chosen intervals. Each interval was 1.5 seconds long, and two intervals were separated by a 1.5 seconds silent period. The two intervals were presented 1.5 seconds after listeners initiated a trial by pressing the middle button on a button box. Lights on the box above two other buttons indicated when an interval occurred; the listener's task was to determine which of the two intervals contained the babble segment. The participant indicated his choice by pressing one of the two buttons below the lights. Immediate feedback was provided by a flashing light associated with the interval containing the babble. A three down, one up adaptive technique was used to determine the babble threshold. In this procedure, after starting with the babble at 50 dB SPL, a level audible for all participants, the level was reduced with every three correct responses and increased with every incorrect response. Each change in direction was considered a "reversal". The level of babble at the final 8 reversals was averaged to obtain the individual babble threshold. The three down, one up adaptive technique has been found to produce a 79% correct performance level (Levitt, 1971). In the experiment the word lists were always presented 50 dB SPL above the individual babble threshold.

The younger adults' babble threshold in the left ear (mean threshold = 15.60 dB, S.D. = 3.50) was significantly ($p < .009$) lower than that of older adults (mean threshold = 22.69 dB, S.D. = 6.86). The same applied to the right ear. There, differences were even bigger. Younger participants achieved a mean threshold of 15.41 dB (S.D. = 4.38), whereas older participants□ mean threshold was 25.45 dB (S.D. = 7.10). This difference was also highly significant ($p < .001$).

Word identification. The material was presented aurally to the left earphone of a matched set of TDH 49 earphones. During all experiments participants were seated in a single walled sound attenuating chamber. The subjects were asked to listen to 10 word lists, each containing 40 words. The word lists were presented at different jitter levels and were randomly assigned within each subject. The jitter levels were counterbalanced within each subject such that each subject listened twice to each jitter level (6, 7, 8, 9, and 10). The words were presented one at a time, an interval containing a word was five seconds long. Participants were told that they would be listening to words that had been distorted so that it could be difficult to understand some words. The subjects were instructed to repeat each word into a microphone immediately after hearing it and were encouraged to guess if they did not hear a word properly. There were no practice trials and no feedback was given about the accuracy of the response. Since the participants were repeating words immediately, there was no memory component in this experiment. Participants were encouraged to ask for a break after completing a list, there was a break for all subjects after the presentation of the fifth list.

The experimenter was positioned outside the booth monitoring the performance via headphones connected to the microphone inside the booth. The experimenter checked the subject's answers from a list containing all words presented. Miss-recognized words were noted.

Results and Discussion

The mean percentages and standard deviations of correctly repeated words as a function of jitter level and age are shown in Table 1. The data were submitted to a 2 (age) X 5 (jitter level) mixed analysis of variance (ANOVA). Age was a between-subject factor and jitter level was varied within each subject. A significant main effect of jitter level [$F(4,15) = 6.85$, $p <$

Table 1.

Percentage correct and standard deviation of word identification performance as a function of age in Experiment 1.

	Age group			
	Younger		Older	
Jitter Level	M	SD	M	SD
Jitter Level 6	92.88	6.80	92.88	4.53
Jitter Level 7	91.63	6.18	89.75	6.92
Jitter Level 8	91.00	5.13	90.00	4.00
Jitter Level 9	86.75	8.70	87.38	3.36
Jitter Level 10	84.13	7.68	83.75	8.19

.002] was revealed and confirmed that the manipulation of temporally distorting the stimuli to different extends had a reliable effect on their intelligibility. Moreover, neither the main effect of age [F(1,18) < 1] nor the interaction between jitter level and age [F(4,15) < 1] were significant. This suggests that the temporal distortion of the words had the same effects on both age groups.

Testing the data on linearity revealed a solely linear [F (1,18) = 26.63, p < .000] relation between temporal manipulation and word recognition performance for both age groups. Thus, the higher the amount of jitter the more difficult the recognition of the words. For younger adults, an estimated accuracy of word recognition of 91 % was accomplished exactly at the jitter level 8.

For older adults, the linearity of the data was less apparent. They showed a decrease in word identification performance from jitter level 6 to 7. Their recognition performance stayed approximately the same for jitter level 7 and 8 before it clearly dropped again for the higher levels of distortion. However, the difference in recall for jitter level 7 and 8 between younger and older adults was not reliable. Since the older participants did not reach the 91 % identification accuracy exactly, and jitter level 7 and 8 were not reliably different from one another, jitter level 7 was chosen as distraction level for the second experiment.

Experiment 2

Using the accuracy level for word identification estimated in Experiment 1, participants were now tested in a paired-associate recall paradigm.

Method

Participants

Fifteen young (mean age = 21.07 years, S.D. = 1.67) and 15 old (mean age = 74.80 years, S.D. = 3.65) adults participated in the second part of the study. The young participants were three male and twelve female Erindale College undergraduate students whose age ranged from 19 to 24 years. The older adults were six male and nine female community dwelling citizens whose age ranged from 67 to 82 years. In exchange for their participation, subjects received payment ($10/hour). In the second part of the study, younger (mean number = 16.47 years, S.D. = 1.68) and older (mean number = 14.53 years, S.D. = 2.92) individuals differed significantly ($p < .035$) in years of education. The Mill Hill Synonym Vocabulary Test was administered to all participants. The older subjects (mean score = 15.80, S.D. = 1.78) achieved a significantly ($p < .001$) higher vocabulary score than did the younger (mean score = 13.40, S.D. = 1.68) subjects.

Material and Design

The same digitized words that served as stimuli in Experiment 1 were used in this experiment. In contrast to the preceding experiment, words were now randomly paired, with the constraint that two words that shared an obvious association (e.g. "football" and "helmet") were never paired. A total of 40 lists was presented to each subject. Each list consisted of five word pairs. The cued-recall performance for each of the five possible positions per list was tested eight times during a single session. The order in which the five serial positions were tested was randomized for each subject. However, the order of the list presentation was the same for all participants. For the older group, all words were jittered on a jitter level of 7, the amount of jitter presented to young adults equaled a jitter level of 8. In all experiments the material was presented to the left earphone of a matched set of TDH 49 earphones in a single walled sound attenuating chamber. The words in the Murphy et. al. study were presented at an intensity level of 50 dB SPL above the individual babble threshold. In the current study, words were presented at an intensity level of 40 dB SPL above the individual threshold for spoken words. However, this change is not believed to have any effect on the intelligibility of the speech material.

The experiment was designed with age as a between-subject factor, serial position of cued word recall served as within-subject factor. Fifteen subjects per age group were tested, each completing eight lists per serial position. Thus, a total of 600 data points per age group were collected.

Procedures

As in Experiment 1, vocabulary score, pure-tone air-conduction, and babble threshold were determined for each subject preceding participation in the experiment.

Audiometric Testing. The same procedures and requirements were applied as in Experiment 1. All participants met the criteria. Nevertheless, younger adults had highly significantly (ps < .01 or less) lower audiometric thresholds than older individuals. This applied to all frequencies in the left as well as in the right ear.

Babble Threshold. The same procedure as in Experiment 1 was used in order to determine the babble threshold for the left and right ear. The older adults' babble threshold on the left ear was significantly ($p < .0001$) higher (mean = 22.57 dB, S.D. = 5.00) than that of younger (mean = 14.50 dB, S.D. = 4.49) adults. The results were very similar for the right ear.

Here, older participants achieved a mean threshold of 24.15 dB (S.D. = 6.68), whereas younger participants had a mean threshold of 13.86 dB (S.D. = 5.52). These differences were also highly (p>.0001) significant.

Word recall. The material was presented auditorily to the left earphone of a matched set of TDH 49 earphones. During all experiments participants were seated in a single walled sound attenuating chamber.

Subjects were asked to listen to lists containing five word pairs each. They were instructed to memorize the word pairs and to recall the second word of the pair when cued with the first word. They were also instructed to guess if they are not sure about the correct answer. The experimenter initiated each list. The presentation of the first word pair was preceded by a warning tone (1000 Hz at 90 dB SPL for 500 ms) and 4 seconds of silence. Then, a word pair was presented every 4 seconds. The words in each pair were presented such that there were 100 ms of silence between both words. Four seconds after the onset of the presentation of the last pair, another warning tone was played, followed by a 4 second period of silence. Finally, participants were cued with the first word from one of the 5 previously presented word pairs and were required to recall the second word of the pair. Note, that at recall the cue word was always presented without any jitter. There was no time limit placed on the recall procedure. A new list was not presented until subjects had given an answer.

List order was identical for all subjects. Each serial position was tested an equal number of times (8) during the presentation of the 40 lists. The order of testing the serial positions was independently and randomly assigned to the 40 lists presented to each subject. No practice trials were given.

The experimenter was positioned outside the booth monitoring the performance via headphones connected to the microphone inside the booth. The experimenter wrote down the subject□s answer in response to the cue word. No feedback was provided. Participants were encouraged to ask for a break after the completion of a list. There was a break for all subjects after completing 20 of the 40 lists.

Results and Discussion

Figure 9 shows the proportion of correctly recalled word pairs as a function of serial position of the word pair and age. The graph shows that older adults were inferior to younger adults in recalling word pairs in the first three serial positions. This result replicated Murphy et. al. (2000). Furthermore, it can be seen from Figure 9 that the percentage of correctly remembered words remains approximately constant for the first four serial positions for younger adults before increasing substantially at the fifth serial position. The percentage of words remembered by older adults was lower than that of younger adults in the first three but not the last two serial positions. This pattern of results was partly confirmed by an analysis of variance (ANOVA) with age as a between-subjects and serial position as a within-subjects factor. Results indicated a significant effect of serial position [$F(4,25) = 22.86$, $p < .0001$]. Surprisingly, the main effect of age [$F(1,28) = 2.67$, $p < .114$] and the interaction of serial position X age [$F(4,25) = 1.61$, $p < .204$] were not significant. The non significant main effect of age may have been caused by a lack of power. An effect of this size would have been significant if three times as many subjects would have been tested.

These results suggest that older adults were less efficient at encoding information

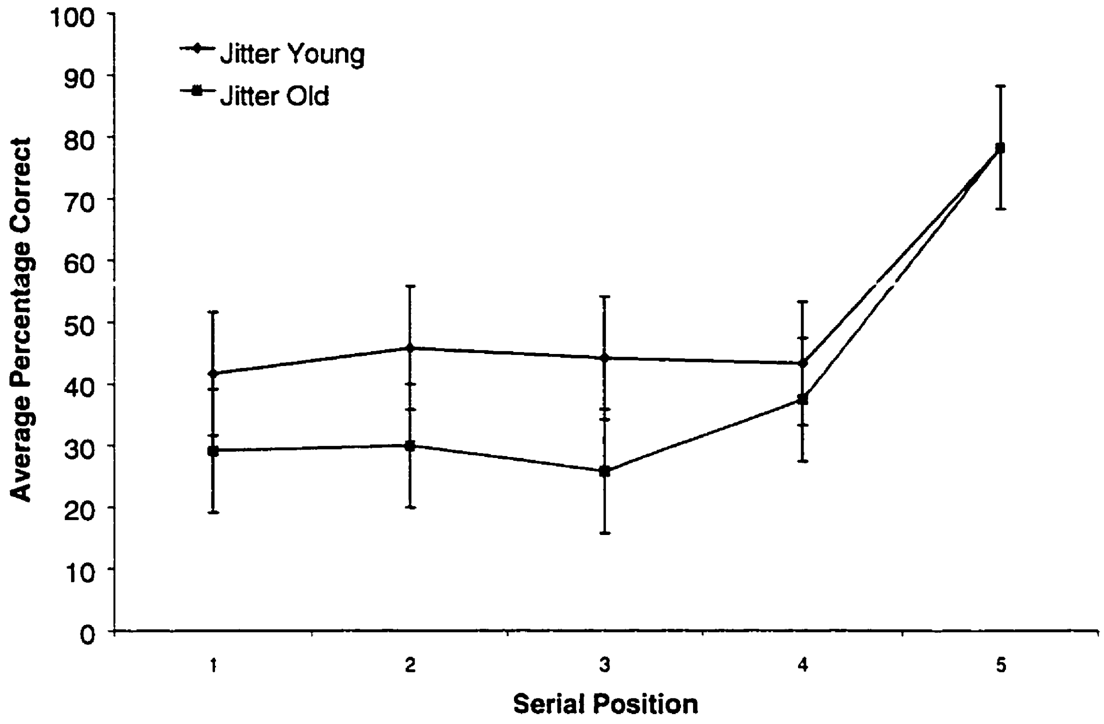

Figure 9. Average percentage correct of word recognition performance as a function of age in Experiment 2. Points represent the mean number of correctly recalled word pairs per serial position; the vertical bars depict standard errors of the means.

into long-term memory than were younger adults. Such a loss of efficiency could account for the older adults' poorer performance in the first three but not the last two serial positions. A possible explanation for the finding is that primary memory representations are equivalent in younger and older adults because they require few attentional resources to be established. On the other hand, recall from the first three serial positions comes from secondary memory, and a lack of attentional resources as in aging results in a less adequate encoding and thus in lower levels of recall.

Figure 10 represents the outcome of the memory performance of younger adults as a function of perceptual manipulation. Specifically, the baseline condition of the Murphy et. at. study, where recall performance was measured using stimuli not distorted or masked in any form, was compared to the outcome of the current study. An ANOVA analyzing both conditions confirmed that there was no significant effect of jitter [$\underline{F}(1, 56) < 1$] suggesting that jitter did not deteriorate memory performance in comparison to the baseline condition. As can be seen in Figure 11 the same result was confirmed for the older adults [$\underline{F}(1,56) < 1$] suggesting that older adults were also not affected by the temporal distortion of the words. Thus, jitter has no effect on memory for either young or old adults, not even at the last serial position, that goes beyond the age effect already confirmed for the baseline condition. Hence, jitter does not appear to affect memory. Comparing the graphs in Figure 12 and conducting a repeated measures analysis of variance (ANOVA) for both, the baseline and the jitter condition (Serial Position (5) X Age (2)X Condition (2)), a significant serial position effect [$\underline{F}(4,53) = 54.28$, $\underline{p} < .0001$], a main effect of age [$\underline{F}(1,56) = 7.421$, $\underline{p} < .009$) and a significant Serial Position X Age interaction [$\underline{F}(4,53) = 3.97$, $\underline{p} < .007$) were confirmed. Again, the main effect of condition was not significant [$\underline{F}(1,56) < 1$]. Note that the main effect of age and the interaction of serial position X

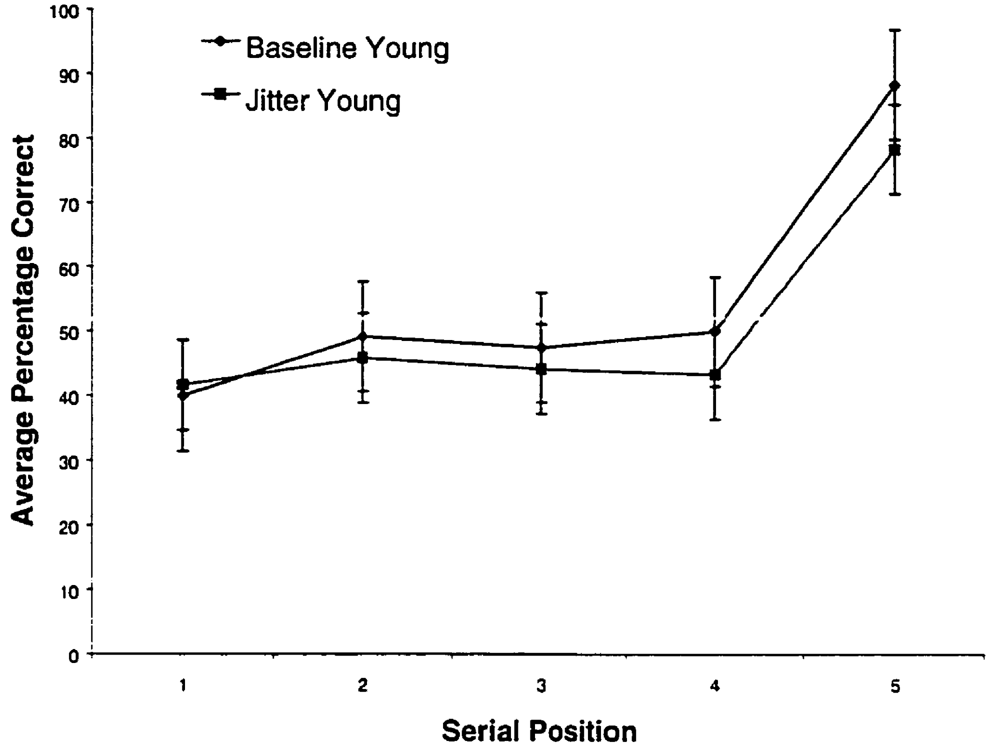

Figure 10. Average number correct of word identification performance in younger adults as a function of perceptual manipulation. Points represent the mean number of correctly recalled word pairs per serial position; the vertical bars depict standard errors of the means.

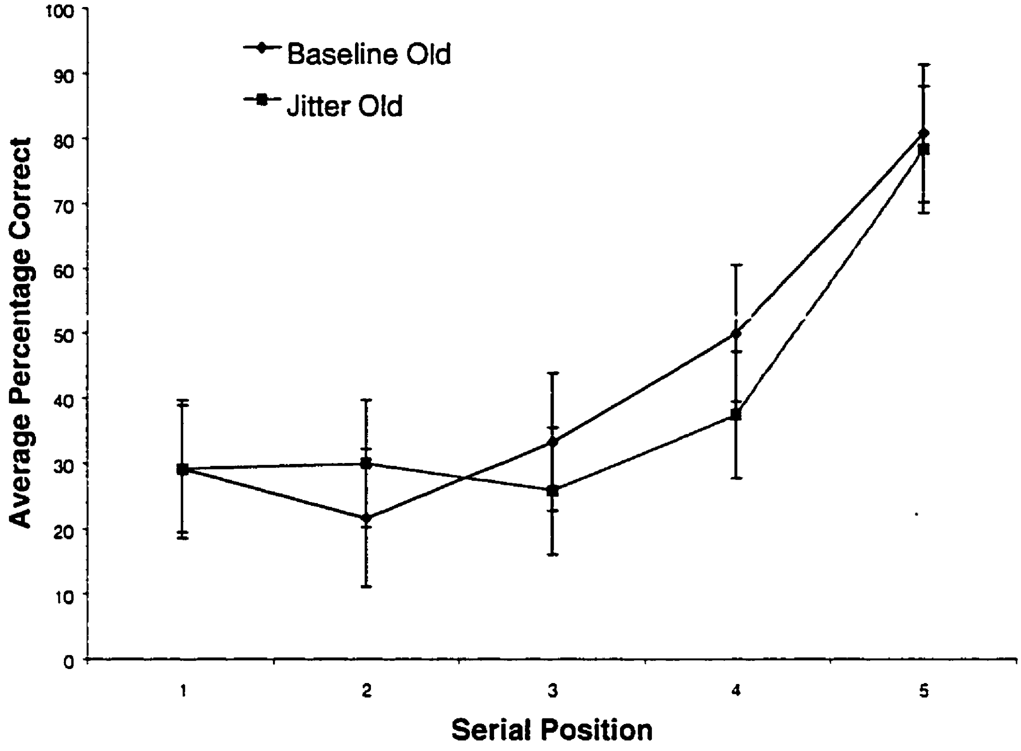

Figure 11. Average number correct of word identification performance in older adults as a function of perceptual manipulation. Points represent the mean number of correctly recalled word pairs per serial position; vertical lines depict standard errors of the means.

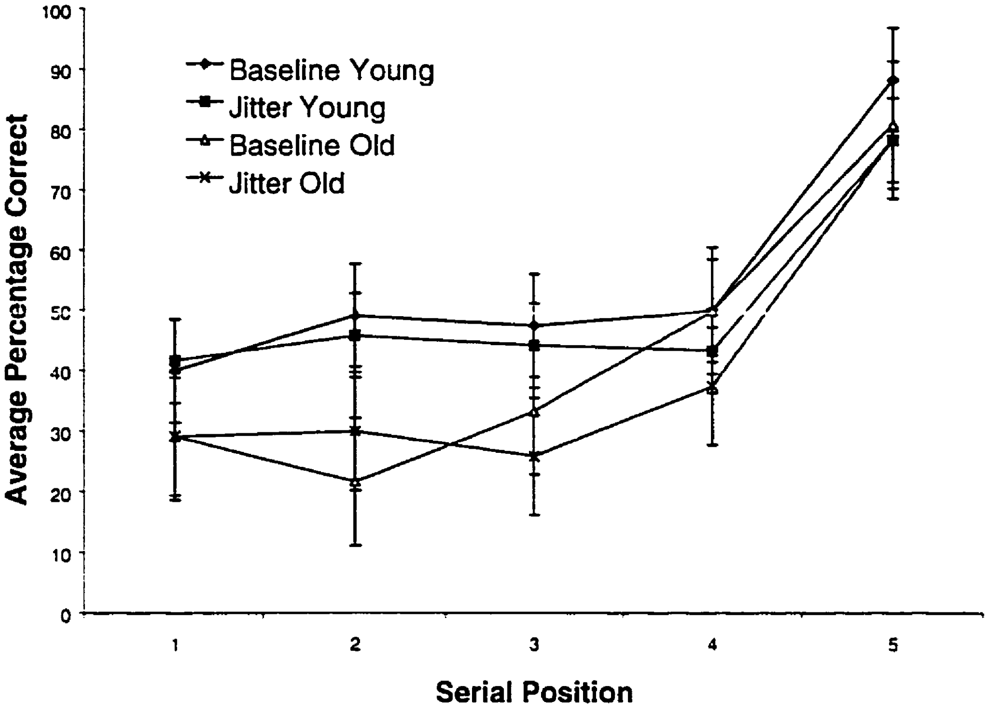

Figure 12. Average number correct of word identification performance as a function of age and perceptual manipulation. Points represent the mean number of correctly recalled word pairs per serial position; vertical lines depict standard errors of the means.

age were not found significant when analyzing the data using the jitter condition only (Figure 9). However, both effects were found significant when analyzing data of both the jitter and the baseline condition (Figure 12). This result can most likely be attributed to a lack of power when analyzing the jitter condition. Whereas the effect size of the main effect age does not exceed 0.351 when computed for the jitter condition alone, it equals 0.763 when the number of subjects is increased due to the comparison of baseline and jitter condition. The same mechanism is most likely responsible for differences in the significance of the Serial Position X Age interaction depending on its analysis in the jitter condition alone or in conjuction with the Murphy et. al. baseline condition. In the analysis of the jitter condition alone, the interaction shows an effect size of 0.422 whereas the same interaction in the comparison of both experiments shows an effect size of 0.879.

General Discussion

Cognitive Decline

A decline of cognitive performance in older adults has been demonstrated in many cognitive aging studies (Charness & Bosman, 1990; Plude & Hoyer, 1985; Salthouse, Kausler, & Saults, 1988 among others). This overall decline has been explained by three major theoretical frameworks. One of the purposes of this study was to investigate age-related decline in perception and cognition, their interactions, and their direct and indirect influence on recall performance.

The results of Experiment 2 (see Figures 9 & 12) show that there was a main effect of age on memory performance indicating that older adults performed less well on the memory task than younger adults. Comparing the obtained results to those found by Murphy et. al. (2000) leads to the conclusion that older participants' recall performance is decreased as opposed to younger participants' performance in all conditions of perceptual manipulation. Specifically, the amount of age-related decline is comparable in all three conditions, baseline, jitter, and babble. However, overall performance of both age groups is lower in the babble as opposed to the baseline and jitter condition.

The results of Experiment 2 support a general age-related decline of cognitive performance as proposed by all three major theoretical frameworks. The results are compared to a similar study conducted by Rabinowitz et. al. (1982) and the limited processing resources approach is used in order to interpret the findings. In their study, Rabinowitz et. al. found a considerable age difference in paired-associate recall especially in the weak-associate condition. Since in the current study words were also paired so that no obvious relationship existed between them the results of both studies can be compared and interpreted in a similar way. Rabinowitz and his colleagues interpreted the decline in recall exhibited by older adults as a less effective integration of the new and unusual relationship between the words in each pair. In the present study, this lack of efficiency at encoding is especially apparent for the encoding of information into secondary memory because age differences in memory can mainly be found in the first three serial positions. Rabinowitz et. al. suggested that effective integration which is important for encoding into secondary memory takes up a considerable amount of processing resources and a lack of those resources as in aging leads to a less elaborate integration of information. Since the impaired processes that are responsible for this outcome seem to be very fundamental it is likely that a main effect of age will always be present in this type of task independent of any other manipulation that may also be effective.

Murphy et. al. demonstrated that the masking of the word pairs by noise decreased memory performance of both younger and older participants. They conducted a 2 (age) X 5 (serial position) ANOVA and found a reliable main effect of age suggesting that the overall memory performance of older adults was poorer than that of younger adults. The absence of an Age X Serial Position interaction suggests that noise had a similar effect on the performance of both younger and older listeners. Moreover, an analysis of variance confirmed that older adults in quiet performed similar to younger adults in noise. The results can be taken as evidence for a differential decline in the babble condition, especially in the first three serial positions, as opposed to the baseline condition for both age groups. Similar conclusions may apply to white noise as a masker.

Taking into account the finding that in the current study no difference in memory between baseline and jitter condition was found, and the finding that in the Murphy et. al. study younger listeners did not show a further decline in performance even with increased perceptual stress seems to support the dysfunctional inhibitory mechanism approach. According to this approach both age groups showed dysfunctional inhibitory mechanisms in the babble condition and thus seemed not be able to focus their attention solely on the processing of the relevant speech material and to completely ignore any other signal as background noise or white noise. The fact that Kester found similar results concerning a decreased memory when masking the stimuli by white noise instead of babble leads to the conclusion that participants did not try to inadvertently make sense of the babble but rather had problems pulling out the words of a general background noise. This would explain why any kind of noise had a similar effect on both groups and performance dropped similarly for both younger and older adults. Testing younger adults in a more difficult babble condition (Experiment 5 Murphy et. al., 2000) did not further degrade their performance. This suggests that inhibitory mechanisms in older listeners are disrupted to a higher degree than in younger listeners, and that this disruption cannot be simulated easily by a higher degree of noise in younger adults.

In the context of this discussion, white noise and babble are seen as different maskers which nevertheless show similar effects. Whereas babble is similar to speech and contains detailed temporal and spectral variations similar to „real speech“, white noise does not show a specially modulated temporal envelope or specific short-term spectral and temporal details of actual speech (Souza & Turner, 1994).

Bearing in mind the result that babble led to a drop in memory performance for both age groups whereas jitter did not seem to have any effect on memory for either young or old adults leads to the conclusion that when maskers are not presented and the material itself is distorted instead, no attentional shift is possible and thus no differential decline of older participants' recall performance can occur. A more detailed interpretation using this approach and an interpretation using an alternative approach will follow in the next section.

Perceptual Decline

Perceptual decline with age is an omnipresent fact and was also present in the sample of older listeners that participated in this study. Although older adults had to meet fairly strict hearing criteria in order to participate in the study it is evident from examining the results that older adults' pure tone thresholds were reliably higher than those of younger participants. Whereas young listeners had mean pure tone thresholds for the speech frequencies (averaged over all frequencies) of 3.00dB HL for the left and 1.39dB HL for the right ear, older listeners' mean pure tone thresholds for the frequencies between 250 and 3000 Hz were as large as 12.94dB HL for the left and 12.00 dB HL for the right ear. Thus, although thresholds of both groups were within "normal" limits the hearing status of younger and older listeners was rather different. This is important to notice because there are indications that pure tone threshold elevations, no matter how mild, cannot be disregarded when testing an older participants' group performance concerning any given auditory function (Divenyi & Haupt, 1997).

Moreover, in the context of attempting to control for hearing loss, it is important to note that normal hearing thresholds in older adults may not ensure a lack of cochlear damage. Schuknecht and Woellner (1955) were able to show that structural ear damage in the auditory system of older listeners can exist that does not have measurable effects on pure tone thresholds. Thus, it is questionable if the hearing status of both age groups were truly comparable.

In Experiment 1 words were temporally distorted to several degrees to investigate the influence of different amounts of jitter on word identification. The goal of the experiment was to find a 91 % accuracy in word identification for both age groups. Since several studies (Schneider, 1997; Dreschler & Plomp, 1985; Ginzel et. al., 1982; Price & Simon, 1984; Tyler et. al., 1982) have contributed evidence that older listeners have a reduced temporal resolution as compared to younger listeners it was expected that, beside a general decrease of word identification performance with an increased amount of temporal distortion, identification difficulties would be differentially elevated for older adults. Thus, older listeners should achieve the required accuracy level with a lower level of external temporal distortion because their perceptual performance should be determined by an interaction between age-related internal jitter and experimental external jitter. Younger listeners, on the other hand, do not suffer from internal temporal distortion to the same extent so that their word identification performance should be determined mainly by the external, experimentally manipulated temporal distortion. At a first sight this hypothesis seems to be confirmed when examining Table 1. Younger adults show a quite linear relationship between temporal distortion and word identification whereas older adults' performance seems to be less clearly related to external jitter. Moreover, the 91 % accuracy was achieved at a jitter level of 8 for younger adults, older participants only needed a jitter level of 7 to achieve a similar accuracy. Confirming these interpretations in a repeated mixed measure analysis of variance however showed a different picture. The only reliable main effect was jitter level whereas neither the main effect of age nor the interaction between jitter level and age were significant. Hence, even though older participants were assumed to be disadvantaged by a reduced internal temporal processing no differential age effect was found.

In a second experiment the paired-associate memory task was presented at the jitter level determined to represent a 91 % accuracy in word recognition. Results showed that there was no difference in memory performance for either age-group when compared to their baseline condition in the Murphy et. al. (2000) study. Thus, neither young nor older subjects were impaired in any form by the temporal distortion as compared to the condition where the word pairs were presented in quiet. This result is surprising in two ways. First, the jitter level in Experiment 2 was chosen such that only 91% of the words were perceived correctly. The remaining 9% of the words that were either incorrectly perceived or completely missed could not be encoded and recalled correctly, thus limiting the maximum recall performance of the words to the 91% correctly perceived words. It is surprising that no reliable difference in recall between baseline and jitter condition was found even though the recall performance in the jitter condition was more severely limited due to lower accuracy in the perception of the words.

Second, using babble as a masker to distort perception of speech material, it has been shown (Pichora-Fuller et. al., 1995; Murphy et. al., 2000) that even after controlling for perceptual identification performance of the words, a differential decline in memory performance of older adults as compared to younger adults was observed. Pichora-Fuller et. al. (1995) suggested that a reallocation of resources towards the perceptual processes to cope with the perceptual manipulation of the stimuli led to the observed age-related decline in memory. It would be interesting to know if the reversal was true for temporal distortion. Thus, no reallocation of resources was necessary in order to cope with jitter because older adults were for one reason or the other better able to adjust to the temporal distortion. The hypothesis that different amounts of processing resources are involved in identifying words with the same accuracy but manipulated by different distortion techniques would have to be tested in an appropriate study.

Another interesting issue concerns the question why a certain technique of perceptual distortion depletes cognitive resources to a greater extent than another technique in order to achieve the same accuracy in word identification. Answering this question can only be speculative for the time being. Mechanisms of perceptual learning might play an important role in the older adults' ability to cope with temporal jitter.

Data from several studies suggested that older adults show reduced monaural temporal processing as compared to younger adults for non speech as well as for speech stimuli. This was even true when peripheral hearing sensitivity was considered clinically normal (Strouse et. al., 1998). Therefore, older adults have plenty of experience with reduced temporal resolution. Improving identification and discrimination performance of distorted stimuli over time is the main issue of perceptual learning studies. A number of studies in the visual (Dosher & Lu, 1998; Lu & Dosher, 1998; Gold, Bennett, & Sekuler, 1999) and auditory (Richards & Zhu, 1995; Tremblay, Kraus, & McGee, 1998; Gundy, 1961; Manatis, 1968; Christensen & Humes, 1997) realm demonstrated that perceptual discrimination improves with practice. This improvement is often specific to the stimulus presented during training. Since more elaborate models are available in the visual realm this research is mainly considered here. Dosher and Lu (1998) and Lu and Dosher (1998) differentiate between internal and external noise and suggest that perceptual learning might involve both kinds of noise. In high noise conditions, improved performance may be associated rather with external noise exclusion whereas in a low noise condition, the improvement may be attributed to stimulus enhancement through internal noise reduction. According to Dosher and Lu (1998), limitations in performance reflecting internal inefficiencies can be quantified in terms of the amount of external noise needed to produce an equivalent performance limitation. Thus, adding small amounts of external noise without changing performance indicates that performance in this stage is not so much limited by external but rather by internal noise. As soon as performance starts changing as a reaction to the addition of external noise, performance is limited rather by external than by internal noise. On the contrary, Gold et. al. (1999) suggest increased efficiency with which participants encoded task-relevant information was a main reason for perceptual learning. Applying these considerations to the internal temporal distortion in the realm of hearing this could mean that older listeners supposedly learn how to handle an age-related increase of the amount of internal jitter by using the mechanisms of perceptual learning. Performance could be enhanced either by extracting more of the potential signal alone (Gold et. al., 1999) or by additionally reducing additive internal jitter (Dosher & Lu, 1998).

Jittering the word stimuli and thus adding external noise reduced temporal resolution. Assuming that enough external noise was added in order to influence performance, performance should change directly in relation to the amount of external noise added. This result was confirmed in Experiment 1 by a significant effect of jitter level on word identification. However, no age differences in perceptual performance as related to different levels of jitter were found suggesting that older adults were able to cope with the external amount of jitter added to the stimuli to the same extent as younger adults. This is surprising since their internal noise level due to reduced temporal resolution should have been higher to begin with. However, incorporating perceptual learning theories would suggest that older adults are able to reduce internal noise thresholds due to perceptual learning. If, due to perceptual learning, internal noise may be reduced in older adults to a similar level as in younger adults then older adults should show a similar course of performance in relation to added external noise. This interpretation was confirmed by a nonsignificant age difference in Experiment 1.

Even after suggesting an explanation for a lack of age difference in perceptual performance, the question remains unsolved why older adults' memory performance did not further decline in comparison to the baseline condition especially since a differential decline of older adults' memory performance was frequently found after equating perceptual performance in noise. This result suggests that, unlike the noise condition, processing resources of older adults did not have to be reallocated to perceptual processes in order to achieve a certain accuracy. Supposedly, it is easier for older participants to deal with temporal distortion than it is to deal with noise maskers because temporal distortion is inherent to their perceptual system and perceptual learning mechanisms serve to improve performance in an automatic, and non effortful way.

However, there is another possible explanation for the higher level of memory performance in the jitter as opposed to the babble condition that does not involve perceptual learning. It is possible that the perception of the words in the jitter condition was less effortful because the words were heard clearly but sometimes wrongly so that no special perceptual effort was required to perceive the words. In the babble condition, on the other hand, perceiving any word was effortful and required additional mental resources.

Maskers as white noise and multi-talker babble decreased memory performance of both younger and older adults as compared to the baseline condition (Murphy et. al., 2000, Kester). Furthermore, there seems to be no qualitative difference in the effectiveness of masking between multi-talker babble and white noise. Pichora-Fuller et. al. (1995) interpreted the results in a memory task achieved by using a multi-talker babble as being caused by a reallocation of limited processing resources towards the perception process. This reallocation decreased memory performance for both age groups as compared to the baseline condition.

Comparing memory performance after manipulating perception either by temporal distortion or by masking suggests two different underlying mechanisms to deal with the manipulation. In general, temporal distortion seems to be less effortful for both younger and older adults resulting in an equivalent performance as compared to the baseline condition. Moreover, older adults may have developed perceptual learning mechanisms in order to efficiently handle higher amounts of temporal distortion omnipresent in their perceptual system. The masking of stimuli cannot be dealt with so efficiently. This may be the case because masking is a perceptual phenomenon frequently happening in everyday perception but not inherent to the perceptual system so that perceptual learning cannot develop. Thus, masking noise or babble are entirely external stimuli for both younger and older adults and not presented long enough or experienced so often in order to develop learning mechanisms. In this case, the effortfulness of perception is entirely determined by characteristics of the masker.

Looking at the question why memory seems to be similarly affected by babble and white noise leads to the conclusion that the similarity between white noise and multi-talker babble might be the absence of "quiet spots" in both which makes it hard and effortful to detect speech sounds (Souza & Turner, 1994). According to Souza and Turner, it should be less resource demanding to mask speech stimuli by a multi-talker babble with fewer voices since this is more likely to result in "quiet spots" in which speech sounds could be more easily detected. Continuous white noise, on the other hand, never allows "quiet spots" and thus should always be a very resource demanding masker. Since older adults' processing resources are more severely restricted than those of younger adults, resource demanding maskers should have a more deleterious effect on their memory performance leading to differentially greater age differences.

Methodological problems and nuisance variables in cognitive aging studies

In the last section some methodological questions in connection with the present study as well as fundamental methodological problems associated with aging research are discussed. I start with questions relevant to the current study before going on to more general issues.

A main problem concerning the experimental design of the memory task used in this study involves the question why a 100% memory performance can never be reached, not even in the last serial position in quiet. Instead of representing a memory task, the presentation of the fifth word pair at each list should represent an identification task because recall is carried out immediately after the presentation of this word pair. Nevertheless, recall performance in younger adults never exceeds 88%, in older adults 81% (Murphy et. al.). This finding could be due to a silent period of 4 seconds at the end of the presentation of the fifth word pair. This would be unfortunate because the M&M paradigm (Madigan & McCabe, 1971) should yield a 100% performance at the last serial position.

Another question emerging from the findings is the fact that jitter has no apparent effect on memory for either younger or older participants, not even at the last serial position. This result is surprising because assuming that the last serial position represents an identification rather than a memory task, and identification was lowered by the perceptual manipulation of the stimulus material to a 91% accuracy level, it is interesting to see that this manipulation does not influence the performance score. Even if jitter has no further effect on memory it should yield a parallel memory function to the baseline/quiet condition of the Murphy et. al. study that is depleted by 9%; the 9% by which identification was lowered after temporally distorting the stimulus material.

Maybe the subject samples in both experiments were not comparable such that subjects presented with the jitter condition in the study conducted by Murphy et. al. would have shown this drop in comparison to the baseline condition or, the other way around, subjects in the current study presented with the quiet condition would have shown a 9% increase in memory performance as compared to the participants of the Murphy et. al. study.

Thus, in order to confidently draw conclusions from the results obtained it would have been important to either test the same subjects in all three perceptual conditions (quiet, babble, and jitter), or at least to incorporate all three conditions into one experiment.

After having raised a few questions concerning the present study, some more general issues related to aging research are mentioned. Investigating cognitive abilities of older adults involves certain methodological difficulties that have to be borne in mind when interpreting results. Sliwinski and Buschke (1997) for instance argued that unrecognized preclinical dementia, that cannot be readily diagnosed but can only be discovered in longitudinal studies, has been shown to contamine estimates of aging effects in well-screened and presumably undemented samples of healthy older adults (Sliwinski et. al., 1996). The present study has to deal with this problem. In order to investigate age effects participants belonging to two extreme age groups, students and seniors, were tested. Age effects are usually interpreted as resulting entirely from cognitive aging. It is not possible to control or even test for preclinical dementia. Hence, the possibility of the contamination of age effects cannot be entirely ruled out. It cannot be determined if and how large the influence of this form of dementia might be on the age effects in a particular study.

A second problem that arises in every study which measures something is the test-retest reliability issue. Usually, information about reliability is not available for memory tests. This lack of information makes it impossible to tell whether differences across age represent variations in mental contents that exceed what would be expected if individuals within an age group were tested on two occasions (Light, 1992). This leaves a little bit of uncertainty on every interpretation of age-related memory differences.

A third problem arises from the fact that recall performance is always measured in a binary way (right/wrong) whereas speed data for instance are measured in a continuous way. According to Verhaeghen & Marcoen (1993), reliability of binary measures can never be expected to be as high as that of continuous measures simply because their measurement is less accurate. Thus, since this study worked with binary measures (the identification or recall of a word or word pair was either right or wrong) the reliability of the measures is probably decreased. This intensifies the reliability problem connected to memory tests.

References

American National Standards Institute. (1989). Specification for audiometers (ANSI S3.6-1989). New York: ANSI.

Anderson, C.M.B., & Craik, F.I.M. (1974). The effect of a concurrent task on recall from primary memory. Journal of Verbal Learning and Verbal Behavior, **13**, 107-113.

Anderson, N.D., Craik, F.I.M., & Naveh-Benjamin, M. (1998). The attentional demands of encoding and retrieval in younger and older adults: Evidence from divided attention costs. Psychology and Aging, **13**, 405-423.

Baeckman, L. & Dixon,R.A. (1992). Psychological compensation: A theoretical framework. Psychological Bulletin, **112**, 259-283.

Baltes, P.B. (1987). Theoretical propositions of life-span developmental psychology: On the dynamics of grows and decline. Developmental Psychology, **23**, 611-626.

Baltes, P.B. & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: a new window to the study of cognitive aging? Psychology and Aging, **12**, 12-21.

Barr, R. A., & Giambra, L. M. (1990). Age-related decrement in auditory selective attention. Psychology and Aging, **5**, 597-599.

Bergman, M. (1980). Aging and the perception of speech. Baltimore: University Park Press.

Bilger, R.B., Nuetzel, M.J., Rabinowitz, W.M., & Rzeczkowski, C. (1984). Standardization of a test of speech perception in noise. Journal of Speech and Hearing

Research, **27**, 32-48.

Burke, D.M. & Light, L.L. (1981). Memory and aging: The role of retrieval processes. Psychological Bulletin, **90**, 513-546.

Buus, S. & Florentine, M. (1985). Gap detection in normal and impaired listeners: The effect of level and frequency. In A. Michelson (Ed.), Time resolution in auditory systems. Berlin: Springer Verlag.

Cerella, J. (1990). Aging and information processing rate. In J.E. Birren & K.W. Schaie (Eds.), Handbook of the psychology of aging (3rd ed., pp. 201-221). San Diego, CA: Academic Press.

Cerella, J., Poon, L.W., & Williams, D.M. (1980). Age and the complexity hypothesis. In L.W. Poon (Ed.), Aging in the 1980's (pp.332-340). Washington, DC: American Psychological Association.

Charness, N. & Bosman, E.A. (1990). Human factors and design for older adults. In J.E. Birren & K.W. Schaie (Eds.), Handbook of the psychology of aging (3rd ed., pp. 446-463). New York: Academic Press.

Christensen, L.A. & Humes, L.E. (1997). Identification of multidimensional speech cues and the effects of training. Journal of the Acoustical Society of America, **102**, 2297-2310.

Cohen, G. (1979). Language comprehension in old age. Cognitive Psychology, **11**, 412-429.

Cohen, G. (1981). Inferential reasoning in old age. Cognition, **9**, 59-72.

Cohen, G. (1987). Speech comprehension in the elderly: The effects of cognitive changes. British Journal of Audiology, **21**, 221-226.

Craik, F.I.M. (1983). On the transfer of information from temporary to permanent memory. Philosophical Transactions of the Royal Society, London, Series B, **302**, 3341-3359.

Craik, F.I.M. (1986). A functional account of age differences in memory. In F. Klix & H. Hagendorf (Eds.), Human memory and cognitive capabilities (pp. 409-422). Amsterdam: Elsevier.

Craik, F.I.M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resourses. In F.I.M. Craik & S. Trehub (Eds.), Aging and cognitive processes, (pp. 191-211), New York: Plenum Press.

Craik, F.I.M. & McDowd, J. (1987). Age differences in recall and recognition. Journal of Experimental Psychology: Learning, Memory, and Cognition, **13**, 474-479.

Craik, F.I.M. & Rabinowitz, J.C. (1985). The effects of presentation rate and encoding task on age-related memory deficits. Journal of Gerontology, **40**, 309-315.

Craik, F.I.M. & Simon, E. (1980). Age differences in memory: The roles of attention and depth of processing. In L.W. Poon, J.L. Fozard, L.S. Cermak, and L.W. Thompson (Eds.), New directions in memory and aging: Proceedings of the George A. Talland Memorial Conference. Hillsdale, N.J.: Erlbaum.

Denney, N.W. & Larson, J.E. (1994). Aging and episodic memory: Are elderly adults less likely to make connections between target and contextual information? Journal of Gerontology: Psychological Sciences, **49**, P270-P275.

Divenyi, P.L. & Haupt, K.M. (1997). Audiological correlates of speech understanding deficits in elderly listeners with mild-to-moderate hearing loss. III. Factor representation. Ear and Hearing **18**, 189-201.

Dosher, B.A. & Lu, Z.-L. (1998). Perceptual learning reflects external noise filtering and internal noise reduction through channel reweighting. Proceedings of the National Academy of Sciences, **95**, 13988-13993.

Dreschler, W.A. & Plomp, R. (1985). Relations between psychological data and speed perception for hearing impaired subjects. Journal of the Acoustical Society of America, **78**, 1261-1270.

Dubno, J.R., Dirks, D.D., & Morgan, D. E. (1984). Effects of age and mild hearing loss on speech recognition. Journal of the Acoustical Society of America, **76**, 87-96.

Duquesnoy, A.J. (1983). Effect of a single interfering noise or speech source upon the binaural sentence intelligibility of aged persons. Journal of the Acoustical Society of America, **74**, 739-743.

Erber, J.T. (1974). Age differences in cognition memory. Journal of Gerontology, **29**, 177-181.

Festen, J.M. & Plomp, R. (1983). Relations between auditory functions in impaired hearing. Journal of the Acoustical Society of America, **73**, 652-662.

Foos, P.W. (1989). Adult age differences in working memory. Psychology and Aging, **4**, 269-275.

Ginzel, A., Pedersen, C.B., Spliid, P.E., & Andersen, E. (1982). The role of temporal factors in auditory perception of consonants and vowels. Journal of Scandinavian Audiology,

11, 93-100.

Glasberg, B.R. & Moore, B.C.J. (1989). Psychoacoustic abilities of subjects with unilateral and bilateral cochlear impairments and their relationship to the ability to understand speech. Journal of Scandinavian Audiology, **32**, 1-25.

Gold, J., Bennett, P.J., & Sekuler, A.B. (1999). Signal but not noise changes with perceptual learning. Nature, **402**, 176-178.

Gordon-Salant, S. (1986). Recognition of natural and time/intensity altered CVs by young and elderly subjects with normal hearing. Journal of the Acoustical Society of America, **80**, 1599-1607.

Gordon-Salant, S. & Fitzgibbons, P.J. (1997). Selected cognitive factors and speech recognition performance among young and elderly listeners. Journal of Speech, Language, and Hearing Research, **40**, 423-431.

Gundy, R.F. (1961). Detection of an unspecified signal: A study in auditory discrimination learning. Dissertation Abstracts, **22**, 2077.

Hale, S., Myerson, J., & Wagstaff, D. (1987). General slowing of non-verbal information processing: Evidence for a power law. Journal of Gerontology, **42**, 131-136.

Hargus, S.E. & Gordon-Salant, S. (1995). Accuracy of speech-intelligibility index predictions for noise-masked young listeners with normal-hearing and for elderly listeners with hearing impairment. Journal of Speech and Hearing Research, **38**, 234-243.

Hasher, L. & Zacks, R.T. (1979). Automatic and effortful processes in memory. Journal of Experimental Psychology: General, **108**, 356-388.

Hasher, L., & Zacks, R.T. (1988). Working memory, comprehension and aging: A review and a new view. In G.H. Bower (Ed.), The psychology of learning and motivation (Vol.22, pp. 193-225). New York: Academic Press.

Helfer, K.S. & Huntley, R.A. (1991). Aging and consonant errors in reverberation and noise. Journal of the Acoustical Society of America, **90**, 1786-1796.

Helfer, K.S. & Wilber, L.A. (1990). Hearing loss, aging, and speech perception in reverberation and noise. Journal of Speech and Hearing research, **33**, 149-155.

Hess, T.M. (1990). Aging and schematic influences on memory. In T.M. Hess (Ed.), Aging and cognition: Knowledge organization and utilization (pp. 93-160). Amsterdam: North Holland.

Hess, T.M., Donley, J., & Vandermaas, M.O. (1989). Aging-related changes in the processing and retention of script information. Experimental Aging Research, **15**, 89-96.

Hultsch, D.F., Hertzog, C., & Dixon, R.A. (1990). Ability correlates of memory performance in adulthood and aging. Psychology and Aging, **5**, 356-368.

Humes, L.E. (1996). Speech understanding in the elderly. Journal of the Amerivan Academy of Audiology, **7**, 161-167.

Humes, L.E. & Christopherson, L. (1991). Speech identification difficulties of hearing-impaired elderly persons: The contributions of auditory-processing deficits. Journal of Speech and Hearing Research, **34**, 686-693.

Humes, L.E., Watson, B.U., Christensen, L.A., Cokely, C.A., Halling, D.A., & Lee, L. (1994). Factors associated with individual differences in clinical measures of speech recognition among the elderly. Journal of Speech and Hearing Research, **37**, 465-474.

Kahneman, D. (1973). Attention and Effort. Englewood Cliffs, NJ: Prentice-Hall.

Kester, J. (2000). Memory and noise. Unpublished study.

Kliegl, R. & Lindenberger, U. (1993). Modeling intrusions and correct recall in episodic memory: Adult age differences in encoding of list context. Journal of Experimental Psychology: Learning, Memory, and Cognition, **19**, 617-637.

Kucera, H., & Francis, W.N. (1967). Computational analysis of present-day American English. Providence, RI: Brown University Press.

Kwong See, S., & Ryan, E.B. (1996). Cognitive mediation of discourse processing in later life. Journal of Speech-Language Pathology and Audiology, **20**, 109-117.

Levitt, H. (1971). Transformed up-down methods in psychoacoustics. Journal of the Acoustical Society of America, **49**, 467-477.

Light, L.L. (1992). Interactions between memory and language in old age. In J.E. Birren & K.W. Schaie (Eds.), Handbook of the psychology of aging (3rd ed.) (pp.275-290). San Diego: Academic Press.

Light, L.L. & Albertson, S.A. (1988). Comprehension of pragmatic implications in young and older adults. In L.L.Light & D.M. Burke (Eds.). Language, memory, and aging (pp. 133-153). New York: Cambridge University Press.

Light, L.L. & Burke, D.M. (1988). Patterns of language and memory in old age. In L.L. Light & D.M. Burke (Eds.), Language, memory, and aging (pp.244-271). New York: Cambridge University Press.

Lindenberger, U. & Baltes, P.B. (1994). Sensory functioning and intelligence in old age: A strong connection. Psychology and Aging, **9**, 339-355.

Lu, Z.-L. & Dosher, B.A. (1998). External noise distinguishes attention mechanisms. Vision Research, **38**, 1183-1198.

Manatis, J.V. (1968). Transfer effects in perceptual learning: A comparison of recognition and discrimination. Dissertation Abstracts International, **28(9-B)**, 3900.

McDowd, J.M. & Craik, F.I.M. (1988). Effects of aging and task difficulty on divided attention performance. Journal of Experimental Psychology: Human Perception and Performance, **14**, 267-280.

Moore, B.C.J. (1989). An Introduction to the Psychology of Hearing. London: Academic Press.

Moore, B.C.J. (1998). Cochlea hearing loss. London: Athenaeum Press.

Moore, B.C.J. & Glasberg, B.R. (1988). Gap detection with sinusoids and noise in normal, impaired, and electrically stimulated ears. Journal of the Acoustical Society of America, **83**, 1093-1101.

Moore, B.C.J, Peters, R.W., & Glasberg, B.R. (1992). Detection of temporal gaps in sinusoids by elderly subjects with and without hearing loss. Journal of the Acoustical Society of America, **92**, 1923-1932. Murphy, D.R., Craik, F.I.M., Li, K.Z.H., & Schneider, B.A. (2000). Comparing the effects of aging and background noise on short-term memory performance. Psychology and Aging, **15**.

Nabelek, A.K. (1988). Identification of vowels in quiet, noise, and reverberation:

Relationships with age and hearing loss. Journal of the Acoustical Society of America, **84**, 476-484.

Nettelbeck, T. & Rabbitt, P.M.A. (1992). Aging, cognitive performance, and mental speed. Intelligence, **16**, 189-205.

Park, D.C. (1992). Applied cognitive aging research. In F.I.M. Craik & T.A. Salthouse (Eds.), The handbook of Aging and cognition.

Park, D.C., Puglisi, J.T., Smith, A.D., & Dudley, W. (1987). Cue utilization and encoding specificity in picture recognition by older adults. Journal of Gerontology, **42**, 423-425.

Park, D.C., Smith, A.D., Dudey, W.N., & Lafronza, V.N. (1989). Effects of age and a divided attention task presented during encoding and retrieval on memory. Journal of Experimental Psychology: Learning, Memory, and Cognition, **15**, 1185-1191.

Park, D.C., Smith, A..D., Lautenschlager, G., Earles, J.L., Frieske, D., Zwahr, M., & Gaines, C.L. (1996). Mediators of long-term memory performance across the life span. Psychology and Aging, 621-637.

Pichora-Fuller, M.K., Schneider, B.A., & Daneman, M. (1995). How young and old adults listen to and remember speech in noise. Journal of the Acoustical Society of America, **97**, 593-608.

Pickles, J.O. (1988). An introduction to the physiology of hearing. (2nd ed.) London: Academic Press.

Plude, D.J. & Hoyer, W.J. (1985). Attention and performance: Identifying and localizing age deficits. In N. Charness (Ed.), Aging and human performance (pp. 47-99). New

York: Wiley.

Price, P.J. & Simon, H.J. (1984). Perception of temporal differences in speech by normal-hearing adults: Effects of age and intensity. Journal of the Acoustical Society of America, **72**, 405-410.

Puglisi, J.T., Park, D.C., Smith, A.D., & Dudley, W.N. (1988). Age differences in encoding specificity. Journal of Gerontology: Psychological Sciences, **43**, P145-P150.

Rabbitt, P.M.A. (1965). An age related decrement in the ability to ignore irrelevant information. Journal of Gerontology, **20**, 233-238.

Rabbitt, P.M.A. (1968). Channel capacity, intelligibility and immediate memory. Quarterly Journal of Experimental Psychology, **20**, 241-248.

Rabbitt, P.M.A. (1991). Mild hearing loss can cause apparent memory failures which increase with age and reduce with IQ. Acta Otolaryngolica, Supplement 476, 167-176.

Rabinowitz, J.C., Craik, F.I.M., & Ackerman, B.P. (1982). A processing resource account of age differences in recall. Canadian Journal of Psychology, **36**, 325-344.

Ryan, E.B., Giles, H., Bartolucci, G., & Henwood, K. (1986). Psycholinguistic and social psychological components of communication by and with the elderly. Language and Communication, **6**, 1-24.

Saito, S. & Nakata, K. (1985). Fundamentals of speech signal processing. Tokyo: Academic Press.

Salthouse, T.A. (1985). Speed of behavior and its implications for cognition. In J.E. Birren & K.W. Schaie (Eds.), Handbook of the psychology of aging (pp.400-426). New York:

Van Nostrand Reinhold.

Salthouse, T.A. (1987). Age, experience, and compensation. In C. Schooler & K.W. Schaie (Eds.), Cognitive functioning and social structure over the life course. Norwood, NJ: Ablex.

Salthouse, T.A. (1992). Mechanisms of age-cognition relations in adulthood. Hillsdale, NJ: Erlbaum.

Salthouse, T.A. (1993). Influence of working memory on adult age differences in matrix reasoning. The British Journal of Psychology, **84**, 171-199.

Salthouse, T.A.. (1994). Aging Associations: Influence of Speed on Adult Age Differences in Associative Learning. Journal of Experimental Psychology: Learning, Memory, and Cognition, **20**, 1486-1503.

Salthouse, T.A. (1996). The nature of the influence of speed on adult age differences in cognition. Developmental Psychology, **30**, 240-259.

Salthouse, T.A., Kausler, D.H., & Saults, J.S. (1988). Investigation of student status, background variables, and the feasibility of standard tasks in cognitive aging research. Psychology and Aging, **3**, 29-37.

Schneider, B.A. (1997). Psychoacoustics and aging: Implications for everyday listening. Journal of Speech-Language Pathology and Audiology, **21**, 111-124.

Schneider, B.A., Daneman, M., Murphy, D.R., & Kwong See, S. (**2000**). Listening to discourse in distracting settings: The effects of aging. Psychology and Aging, **15**, 110-125.

Schneider, B.A., Pichora-Fuller, M.K., Kowalchuk, D., & Lamb, M. (1994). Gap detection and the precedence effect in young and old adults. Journal of the Acoustical Society of America, **95**, 980-991.

Schneider, W. & Shiffrin, R.M. (1977). Controlled and automatic human information processing: 1. Detection, search, and attention. Psychological Review, **84**, 1-66.

Schuknecht, H.F. & Woellner, R.C. (1955). An experimental and clinical study of deafness from lesions of the cochlea nerve. Journal of Laryngology and Otology, 75-97.

Sliwinski, M. & Buschke, H. (1997). Processing speed and memory in aging and dementia. Journals of Gerontology, **52B**, 308-318.

Sliwinski, M., Lipton, R.B., Buschke, H., & Stewart, W.F. (1996). The effects of preclinical dementia on estimates of normal cognitive functioning in aging. Journal of Gerontology: Psychological Sciences, P217-P225.

Snell, K.B. (1997). Age-related changes in temporal gap detection. Journal of the Acoustical Society of America, **101**, 2214-2220.

Snell, K.B. & Frisina, D.R. (2000). Relationships among age-related differences in gap detection and word recognition. Journal of the Acoustical Society of America, **107**, 1615-1626.

Souza, P.E. & Turner, C.W. (1994). Masking of speech in young and elderly listeners with hearing loss. Journal of Speech and Hearing Research, **37**, 655-661.

Speranza, F., Daneman, M., & Schneider, B.A. (2000). How aging affects the reading of words in noisy backgrounds. Psychology and Aging, **15**, 253-258.

Strouse, A., Ashmead, D.H., Ohde, R.N., & Grantham, D.W. (1998). Temporal processing in the aging auditory system. Journal of the Acoustical Society of America, **104**, 2385-2399.

Takasaki, Y. (1991). Digital transmission design and jitter analysis. Boston: Artech House.

Tipper, S.P. (1991). Less attentional selectivity as a result of declining inhibition in older adults. Bulletin of the Psychonomic Society, **29**, 45-47.

Thompson, L.A. (1995). Encoding and memory for visible speech and gestures: A comparison between young and older adults. Psychology and Aging, **10**, 215-228.

Tremblay, K., Kraus, N., & McGee, T. (1998). The time course of auditory perceptual learning: Neurophysiological changes during speech-sound training. Neuroreport: An International Journal for the Rapid Communication of Research in Neuros, **9**, 3557-3560.

Tulving, E. & Thomson, D.M. (1973). Encoding specificity and retrieval processes in episodic memory. Psychological Review, **80**, 352-373.

Tyler, R.S., Summerfield, Q., Wood, E.J., & Fernandes, M.A. (1982). Psychoacoustics and phonetic temporal processing in normal and hearing-impaired listeners. Journal of the Acoustical Society of America, **72**, 740-752.

van Rooij, J.C.G.M., & Plomp, R.(1990). Auditive and cognitive factors in speech perception by elderly listeners. II. Multivariate analyses. Journal of the Acoustical Society of America, **88**, 2611-2624.

van Rooij, J.C.G.M., & Plomp, R. (1992). Auditive and cognitive factors in speech perception by elderly listeners. III. Additional data and final discussion. Journal of the Acoustical Society of America, **91**, 1028-1033.

Verhaeghen, P. & Marcoen, A. (1993). Memory aging as a general phenomenon: Episodic recall of older adults is a function of episodic recall of young adults. Psychology and Aging, **8**, 380-388.

Verhaeghen, P., Marcoen, A., & Goossens, L. (1993). Facts and fiction about memory aging: A quantitative integration of research findings. Journal of Gerontology: Psychological Sciences, **48**, P157-P171.

White, N. & Cunningham, W.R. (1982). What is the evidence for retrieval problems in the elderly? Experimental Aging Research, **8**, 169-171.

Whiting, W.L. IV & Smith, A.D. (1997). Differential age-related processing limitations in recall and recognition tasks. Psychology and Aging, **12**, 216-224.

Wingfield, A. (1996). Cognitive Factors in auditory performance: Context, speed of processing, and constraints of memory. Journal of the American Academy of Audiology, **7**, 175-182.