Aging Working Population: Hearing Impairment a Growing Challenge for the Working Environment

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Abstract. Population developments raise expectations of an aging working population. These create new challenges for the working world. One is to deal with age-related impairments such as hearing impairment which impacts performance due to impairment of speech comprehension, memory performance and can lead to safety risks. In order to compensate this proactively a basic question has to be answered: Are problems in auditory processing and memory performance due to deficits in peripheral hearing or due to age-related or secondary deficits in central processing components? Two studies were conducted to check the role of peripheral factors. Young normal hearing participants have to perform a verbal memory task under different hearing conditions that simulate hearing impairment. The results show significant effects of induced hearing impairment and provide further evidence that verbal memory performance deficits of hearing impaired are based on a peripheral hearing loss/early processing stages and maybe less on central processing components.

Keywords: Aging working population · Hearing impairment · Verbal memory performance

1 Introduction

The population developments in Western industrialized nations raise expectations of an aging of the working population. These create new challenges for the working world. One of the challenges is to deal with age-related impairments such as loss in hearing capacity. The results of a Finnish survey study [1] with participants aged from 54 to 66 years show that 37 % of the participants reported hearing difficulties and 43 % reported difficulties in following a conversation under noisy conditions. Furthermore, it was shown that self-reported hearing loss can be strongly associated with the audiometric measurement in the range of audibility of 4 to 8 kHz. Data of the WHO suggest that 53 % of the people which are 45 years old and older are hearing impaired [2]. This underlines the importance of research in this area for the working world that will be increasingly shaped by older employees.

Various studies have shown that hearing impairment impacts not only the quality of life of the concerned person itself [3–6] as well as all persons with whom the concerned person communicates [7], but also the (job) performance of those affected [8] due to

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impairment of speech comprehension and memory performance. Furthermore, uncorrected reduced hearing can lead to safety risks in everyday situations as well as in the workplace e.g. because warning and/or information signals or environmental noises cannot be heard well enough [9] or instructions are misunderstood. The National Academy on an Aging Society [5] reports that in America only 67 % of the working-age population with impaired hearing is employed whereas, 75 % of the working-age population without hearing impairment is employed. Also, hearing impaired people are often employed in jobs like farming, craft and repair, machine operators or transportation and fewer of them are employed in occupations like administrative, professional, service and/or sales. Furthermore, 18 % of Americans with hearing impairment aged between 51 and 61 are retired whereas only 12 % of the normal hearing Americans go into retirement the same early. In addition hearing impairment can be the result of occupational noise exposure (e.g. in airfield personnel, military personnel) [10].

Impairment of speech comprehension [11] is accompanied by impaired short-term memory, and by more recent theories the transfer from short-term memory to long-term memory, a partial function of the working memory due to losses in the acoustic perception [12–15]. Boxtel et al. [12] suggest "(…) that verbal memory function may be underestimated in individuals with mild to moderate degree of hearing loss." (p. 152). Also, selective attention seems to be impaired by hearing difficulties [16]. Performance comparisons of normal hearing people and people with hearing impairments show performance penalty of selective attention already in mild hearing impairment from 17.5 dB [17].

A number of studies suggest that information processing of people with hearing impairment can often be executed without error, but the information processing is associated with significantly increased effort. McCoy et al. [18] use the so-called "effortfulness hypothesis" [19] to explain deficits in memory performance of hearing impaired people: A hearing impaired must expend a higher performance effort respectively more cognitive resources to achieve the same perceptual performance as a normal hearing person, which leads to lower available process resources to encode the content. The argumentation of McCoy et al. [18] bases on the results of Rabbitt's experiments [20] with noise masked spoken digits. Normal hearing participants showed a poorer recall frequency for digits that were noise masked than for digits without noise. Also, the recall of the first half of a digit list, no matter if they are presented with or without noise masking, was significantly better if the second half of the list was presented without noise masking than with noise masking. Rabbitt [20] explained the results by an increase of effort that is necessary to discriminate between the spoken digits and the noise which leads to less available information processing resources to rehearse and memorize the digits. Also, differences in memory performance between normal hearing and mild hearing impaired participants were shown, even if hearing impaired participants were able to initially recall the used words. McCoy et al. [18] were able to experimentally proof the hypothesis of additional efforts which are needed by hearing impaired. They investigated the recall performance of sets of three words of two different hearing groups: a "better hearing group" (pure tone averages less or equal to 25 dB in the better ear; max. mild hearing impairment) and a "hearing loss group" (pure tone averages greater than 25 dB in the better ear). The results of the serial reproduction task show no memory deficits for words at the final position but for words at the antepenultimate position, and only if the words had low semantic similarity. Thus, the result provides an argument not only for the "effortfulness hypothesis", but also for the "top-down" compensation of such deficits through long-term memory processes. Wingfield, Tun and McCoy [21] emphasize that the effect of the effort must be very powerful because of influencing the memory performance of a really short set of three words.

Frisina and Frisina [22] tested the speech recognition performance of younger (18 – 19 years old) and older adults without hearing impairment and older adults with hearing impairment (three groups: graded degrees of mild high-frequency hearing loss, presbycusis; older adults: 60–81 years old) in quiet and in noisy conditions. Under quiet conditions, younger and older normal hearing adults do not differ in their speech recognition performance. Concerning the four groups of elderly participants the results show that the performance of normal hearing older participants was significant better than the performance of all three elderly hearing impaired groups. Also, the group with the least hearing impairment did perform better than the two other groups with more degree of hearing impairment. But the results look different if noise was added to the presented words: For noise conditions a significant age-affect can be shown for speech recognition performance. In the noise condition younger normal hearing participants perform significant better than older participants without hearing impairment. In addition the performance advantage under quiet conditions of normal hearing older adults compared to older adults with hearing impairment (three groups) disappeared for spondee words and for target words in sentences with supportive context. Only for target words in sentences without supportive context, a better performance of the normal hearing older adults than of all three hearing impaired groups can be shown. Frisina and Frisina [22] point out that the performance differences under noise between normal hearing younger and older participants cannot be explained on differences in peripheral hearing loss. Due to the absence of performance differences between the two normal hearing groups under the quiet conditions they suggest a brainstem auditory dysfunction. The performance deficits of the hearing impaired groups under noise condition can be interpreted as result due to a peripheral hearing loss, a central auditory processing dysfunction due to age and a peripheral hearing-loss induced plasticity occurring at brainstem and cortical levels.

Wong et al. [23] found a neurophysiological proof of the "effortfulness hypothesis": In a word identification task younger and older adults had to identify words in a quiet and two noise conditions (multi-talker babble noise). In comparison to the younger group, older adults show a decreased activation in the auditory cortex but an increased activation in areas that are associated with attention and the working memory, especially under conditions with minor signal-to-noise ratio. Unfortunately, the degree of hearing impairment was not explicitly included resp. not reported in the work of Wong et al. [23].

Often, studies with participants suffering of hearing impairment do investigate samples which consist of elderly people but the results of different research groups indicate that the association between hearing acuity and the performance in a verbal memory task was not dependent on the age of the participants [e.g. 12].

Complementary to the investigation of performance differences of hearing impaired people, some research groups study the impact of hearing aids. Their results give a first indication that the correction of peripheral hearing loss with a hearing aid leads to an increase of working memory capacity [e.g. 24].

Eckert et al. [25] tested 15 normal hearing participants aged from 21 to 75 years in a voice recognition task. To simulate hearing conditions of people with high frequency hearing loss and to vary word intelligibilities, four different low-pass filter conditions were investigated. The results show that the correct word recognition was equivalent across age but did very between the four hearing conditions (% of correct word recognition for low pass filter frequency cutoff 3150 Hz > 1600 Hz > 1000 Hz > 400 Hz).

The findings presented above indicate that different processes contribute to the performance deficits associated with hearing loss. It is necessary to develop a clear and detailed picture of the processes involved to cope with problems that might be associated with reduced hearing proactively. Preventive interventions, training and rehabilitation that improve technical aids have to be developed. For the willingness to use them, and the provision of technical assistive devices, a basic question has to be answered: Are problems in auditory processing and memory performance primarily due to the peripheral hearing loss/early processing stages or are they basically caused by age-related or secondary deficits in central processing components/higher cognitive functions (physiological and/or anatomical changes) of hearing impaired people. Despite many studies, the question has not been definitively answered. Therefore, two studies were carried out: A laboratory experiment and a group study. In both studies young normal hearing participants have to perform a verbal memory task under different hearing conditions that simulate hearing impairment (induced hearing impairment). Young adults were chosen in the first instance to exclude a possible age-effect on information processing (see also [12]).

Both studies tested two research questions: (1) Can differences in the verbal memory performance of normal hearing young adults be shown, depending on different simulated impaired hearing conditions (quiet, interrupted, distorted, background noise) and normal volume (loud = control condition)? (2) If differences in the verbal memory performance exist, which of the four different simulated hearing conditions do lead to which performance difference?

If significant differences in the verbal memory performance of normal hearing young adults can be shown due to induced hearing impairment, this would be a strong indication for a central role of peripheral hearing impairments/impairments of early processing stages. In this case, the use of (well adapted) hearing aids could really improve the situation of hearing impaired.

2 Method

2.1 Study 1: Laboratory Experiment

A laboratory experiment with repeated measures was chosen for Study 1. The study was conducted in an experimental laboratory of the department of psychology of the University of Graz, Austria.

Participants. In total, 31 young adults participated in Study 1. The sample consists of 18 women and 13 men aged between 20 and 31 years with an average age of 24.00 years (*SD* = 2.22). All study participants have a higher level of education (24 with a general qualification for university entrance, 7 with a university degree). The participation in the study was voluntary and all participants provided an informed consent.

Materials. To measure the verbal memory performance five different word lists of the German version [26] of the Auditory Verbal Learning Test (AVLT) [27, 28] were presented via headphones (AKG K240 studio headphones). The Auditory Verbal Learning Test has been successfully used in a study of Boxtel et al. [12]. Every used word list consists of 15 different nouns with low phonetic and semantic similarity. The used playback interval was two seconds per word. The verbal memory performance was operationalized with two performance measures: number of correctly reproduced words and number of errors (frequency of called words that were not part of the particular word list).

Overall, five different hearing conditions (within factors) were investigated in Study 1: four conditions of hearing impairment induced by e.g. reduced volume or additional noise with the levels: quiet, interrupted, distorted, background noise and one control condition (not reduced, loud). To induce these different conditions of hearing impairment the audio files of four of the five word lists have been modified with the help of the software Audacity®. The word list used for the "quiet condition" (induced conductive hearing loss, simulation of the auditory impression of a person with mild to moderate hearing loss) has been reduced in volume on 7 % of the base volume which was used for the word lists of all other conditions. This leads to a sound pressure level of 39 dB for the "quiet condition" and of 65 dB for all other conditions (measured at the headphones, sound pressure level meter SL-100, Voltcraft®). A sound pressure level of 65 dB can be described as normal conversational level. To create an effect of masking of parts and interruptions within of the presented words ("interrupted condition"), 20 % of the total word duration was masked by a silence sequence for each word of the word list of the "interrupted condition". Care was taken not to remove important parts for proper word recognition to avoid malapropisms. For the "distorted condition" (simulation of an age-related change in the periodic encoding) one of the five word lists was divided into two separate audio tracks. With the help of the software Audacity®, the frequencies of the two audio tracks were modified. All frequencies of the first audio track were enhanced by 12 % and all frequencies of the second audio track were reduced by 12 %. After that, both tracks were reassembled into a single track, which leads to a distorted hearing effect. To simulate hearing conditions that can be found in everyday situation, background noise typical for a situation when two persons meet in a café were added as a second audio track to the word list used in the "background noise condition". The two different audio tracks of the "background noise condition" were presented dichotic which means that each audio track was presented at one of the participant's ears.

Procedure. The participants were asked to reproduce all 15 words of the heard word list immediately after the presentation of the whole list. For this, they had a maximum reproduction time of two minutes. Each participant has to hear and reproduce all five tested word lists (five trials/hearing conditions) during the laboratory experiment (repeated measure). The order of the five word lists was permuted over all participants. In order not to make the experiment too strenuous a short break (three minutes) in which the participants could recover, was inserted between the trials.

Statistical Analysis. Analyses of variance with repeated measures were performed for calculating the results. A significance level of 5 % was adopted for the results.

2.2 Study 2: Group Study

Study 2 was planned as replication of Study 1 and was conducted as group study as part of two different courses for undergraduate students at the Hochschule Ruhr West - University of Applied Sciences in Bottrop, Germany.

Participants. The sample of Study 2 consists of 30 participants with normal hearing abilities. Overall, 6 women and 24 men aged between 19 and 29 years (M = 21.73, SD = 2.33) take part in this study. The participation in the study was voluntary and all participants provided an informed consent.

Materials. In order to ensure that Study 2 replicates Study 1, the materials used in Study 2 were, with the exception of the presentation of the word lists, not different from the materials described under the material section of Study 1 (see 2.1 for more details). Due to the execution of Study 2 as group study, the audio tracks of the five different word lists were presented via loudspeakers and not via headphones. Also, the presentation via loudspeakers leads to a change in the presentation mode of the "background noise condition" from a dichotic presentation (Study 1) to a binaural presentation.

Procedure. Study 2 replicated the procedure of Study 1 (see Study 1 for more details). Due to the execution of Study 2 as group study the verbal reproduction of the words after hearing each word list used in Study 1 was changed into a written one.

Statistical Analysis. Analyses of variance with repeated measures were performed for calculating the results. A significance level of 5 % was adopted for the results.

3 Results

3.1 Study 1: Laboratory Experiment

Correct Word Reproduction. An analysis of variance with repeated measures shows that the number of correctly reproduced words was significantly better in the "control condition (loud)" than in the "distorted condition", $F(4, 27) = 3.67$, $p = .041$ (post-hoc test: Sidak, $p < .05$). No significant differences can be shown for all other hearing conditions. The mean values of all five conditions are shown in Table 1.

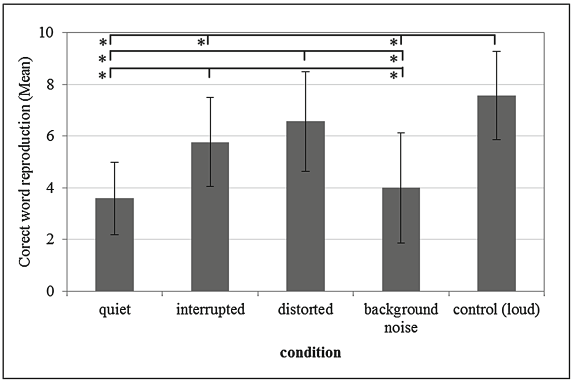
Number of Errors. To show differences of the five hearing conditions in the second verbal memory performance measure, the numbers of errors which is defined as frequency of called words that were not part of the particular word list, an analysis of variance with repeated measures was calculated. The result show no significant number of error differences for the five different hearing conditions, $F(2.78, 83.31) = 1.89$, *ns* (see Table 1).

Table 1. Study 1: Mean correct word reproduction and mean number of errors per each hearing condition.

		Hearing condition				
		Quiet	Interrupted	Distorted	Background noise	Control (loud)
Correct word reproduction	M *(SD)*	8.19 *(3.05)*	8.90 *(2.75)*	**8.35** *(2.68)*	9.16 *(2.19)*	**9.45** *(2.92)*
Number of errors	M *(SD)*	0.97 *(1.11)*	0.45 *(0.57)*	0.61 *(0.88)*	0.55 *(0.81)*	0.58 *(0.99)*

3.2 Study 2: Group Study

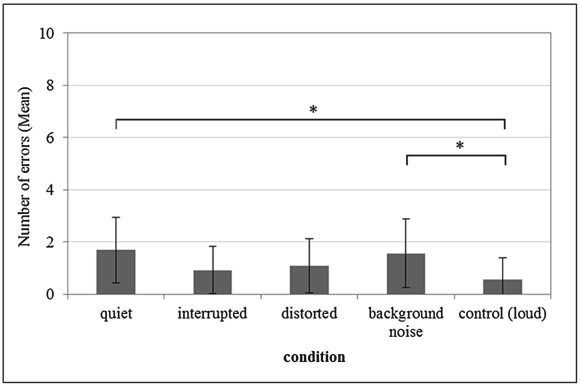
Correct Word Reproduction. The result of an analysis of variance with repeated measures shows that there are some significant differences in the verbal memory performance measured by the number of correctly reproduced words for the five different hearing conditions, $F(4, 26) = 36.55$, $p < .0001$. Post-hoc analyses (Sidak, $p < .05$) show that the number of correctly reproduced words was significantly better in the "control condition (loud)" than in the three conditions "interrupted", "background noise" and "quiet". Also, the number of correctly reproduced words was significant higher in the "distorted condition" than in the two conditions "background noise" and "quiet" and significant higher for the "interrupted condition" than for the two hearing conditions "background noise" and "quiet" (see Fig. 1).



Note. * … $p < .05$, Sidak

Fig. 1. Study 2 – Mean correct word reproduction of the five hearing conditions

Number of Errors. An analysis of variance with repeated measures shows that the number of errors (frequency of called words that were not part of the particular word list) was significantly higher in the two conditions "quiet" and "background noise" than in the "control condition (loud)", $F(4, 26) = 4.37$, $p = .008$ (post-hoc test: Sidak, $p = .041$, see Fig. 2).



Note. * … $p < .05$, Sidak

Fig. 2. Study 2 – Mean number of errors of the five hearing conditions

4 Discussion

In both studies an effect of induced hearing impairment on the verbal memory performance of normal hearing young adults can be shown. Whereas in Study 1 only a significant better number of reproduced words in the "control condition (loud)" compared to the "distorted condition" (simulation of an age-related change in periodic encoding) and no differences in the number of errors made by the participants can be shown, Study 2 resulted in more differences between the varied hearing conditions. The three conditions of induced hearing impairment "interrupted" (masking effect), "background noise" (everyday situation) and "quiet" (simulation of the auditory impression of a person with mild to moderate hearing loss) results in a poorer verbal memory performance (correct word reproduction) of the participants than the "control condition (loud)". Also, the number of errors was significant higher for the two induced hearing impairment conditions "background noise" and "quiet" than for the "control condition (loud)". Overall, the results show that quantitative effects ("loud", "quiet") as well as qualitative effects ("distorted", "interrupted", "background noise") of hearing impairment on the verbal memory performance can be simulated for normal hearing young adults.

The results show that the association between hearing acuity and performance found by Boxtel et al. [12] using the same verbal memory task can be shown for normal hearing young adults under simulated hearing loss, too. For this reason, the results of the two studies provide further evidence that differences in the verbal memory performance can be attributed to a peripheral hearing loss/early processing stages and not primarily on central processing components/higher cognitive functions. Also, they are consistent with the results of Eckert et al. [25] which were able to show an impact of simulated hearing conditions (by low-pass filtering) on the percentage of correct word recognitions in normal hearing participants.

Furthermore, the results support the “effortfulness hypotheses” [18, 19] that additional effort is needed by hearing impaired people (conditions: “distorted condition”, “interrupted”, “background noise”, “quiet”) to achieve the same perceptual performance as normal hearing people (“control condition (loud)”). Interestingly, the effect that can be shown for the “distorted condition” in Study 1 cannot be shown in Study 2 and the effect for the conditions “interrupted”, “background noise” and “quiet” in Study 2 cannot be shown in Study 1. Since care was taken to use the same volume levels in both studies (measured at the headphones/the outer ear of the participants), it is possible that the presentation via headphones supports the simulation of impairment in the “distorted condition” but was not realistic enough to give the participants the same impression than with the presentation via loudspeakers for the other three conditions.

Frisina and Frisina [22] reported significant performance differences between three groups of hearing impaired elderly participants in a speech recognition task. The least impaired group did perform better than the two groups with more degree of hearing impairment. The performance differences that can be shown for the “distorted condition” and the two conditions “background noise” and “quiet” as well as between the “interrupted condition” and the two conditions “background noise” and “quiet” in Study 2 may reflect this too. An interpretation of these effects can be that the “background noise condition” and the “quiet condition” both simulate hearing conditions of greater hearing loss than the two conditions “distorted” and “interrupted”. These results indicate that the concomitants of hearing loss in speech perception are due to complex distortion of perception and not only to volume factors.

To sum it up, the results of the two studies provide further evidence that differences in the verbal memory performance are due to a peripheral hearing loss/early processing stages and not primarily on the impairment of central processing components/higher cognitive functions. The exclusion of possible age-related effects by investigating only young adult participants supports this. The results provide an opportunity to simulate hearing impairment and learn more how to develop new ways of interventions, trainings and rehabilitation as well as for the development of future human-machine-interfaces and technical assistive devices. Also, the research of Lehrl et al. [24] supports the importance of future research in the field of hearing aid design and the fitting of hearing aids. However, the results support the well-known fact on the subject of hearing impairment: A hearing aid that just increases volume/the sound pressure level will not be efficient and may potentially result in discomfort rather than in better performance. As the results of qualitative changes indicate, sound perception is an important secondary component, which also might be primarily due to early process stages of speech perception. Therefore, more research is needed to understand how memory performance demands of hearing impaired people can be improved with the help of new and modern hearing aids. To increase the possibilities of employment of hearing impaired, future studies have to think about occupationally specific hearing conditions to characterize them and to improve the fitting of hearing aids in these special situations. This may have a big impact on employees in working environments like open-plan offices, jobs with customer contact, consulting, teaching and so on as well as for employees in working environments with sound emission (e.g. construction areas, machine operator, airfield personnel,…) or acoustically difficult rooms (e.g. classroom, auditorium, conference room,…). A better fitting of hearing aids may also help to increase the willingness to wear them and improve the present situation that many hearing impaired people do not use a hearing aid or do not use it regularly (see also [5]).

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