Measuring listening effort in the field of audiology – a literature review of methods, part 1

Messungen von Höranstrengung im Bereich der Audiologie – eine literaturgestützte Methodenübersicht, Teil 1

Karin B Klink[1], Michael Schulte[2], Markus Meis[2]
[1]Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany
[2]Hörzentrum Oldenburg GmbH, Oldenburg, Germany

Abstract When studying the audiological literature, it is evident that more and more attention is drawn to listening effort. The literature also shows that listening effort is an additional measuring dimension next to speech intelligibility describing comprehension of speech especially in noisy situations and should therefore be included in the evaluation of noisy listening conditions. The aim of this publication was to review the literature and to give an overview of the different methods employed to measure listening effort. Particular attention was paid to find a practical way to measure listening effort with a special focus on hearing aid evaluations. The keywords »listening effort«, »ease of listening«, »listening comfort« and »listening difficulty« were used in the search. 54 publications about listening effort were reviewed and analyzed according to type of measurement, focus of study, subjects and outcome. Three main types of listening effort measurement were identified: measurements of physiological reactions (especially pupillometry), measurements of cognitive performance, and subjective ratings (direct scaling of listening effort or questionnaires).

In the first part of this review, results from physiological measurements and cognitive performance are reported. In the second part, results from subjective ratings, overview tables of the findings as well as a summary and discussion are presented.

Key words Listening effort, listening difficulty, ease of listening, SNR, pupillometry, dual task paradigm

Zusammenfassung *Bei der Durchsicht der audiologischen Literatur wird deutlich, dass das Thema Höranstrengung zunehmend an Bedeutung gewinnt. Es zeigt sich, dass die Höranstrengung eine zusätzliche Messdimension beim Verstehen von Sprache mit Hintergrundrauschen darstellt und deswegen bei der Evaluation von Geräuschsituationen hinzugezogen werden sollte. Das Ziel dieser Publikation war, in einer Literaturrecherche die verschiedenen Methoden zur Messung der Höranstrengung zusammenzufassen. Ein besonderes Augenmerk war dabei die Suche nach einer praktikablen Methode zur Messung der Höranstrengung vor allem für die Evaluation von Hörgeräten. Die folgenden Schlagwörter wurden bei der Literatursuche benutzt: »listening effort«, »ease of listening«, »listening comfort« und »listening difficulty«. 54 Publikationen wurden im Hinblick auf Messtyp, Fokus der Studie, die Probanden und die Ergebnisqualität ausgewertet. Dabei wurden drei Haupttypen von Messungen identifiziert: Messungen der physiologischen Reaktionen (vor allem Pupillometrie), Messungen der kognitiven Leistungen sowie die Erfassung der subjektiven Bewertung der Höranstrengung (direkte Skalierung oder Fragebogenverfahren).*

Der erste Teil der Literaturübersicht stellt die Ergebnisse von Messungen der physiologischen Reaktionen und kognitiven Leistungen vor. Der zweite Teil beinhaltet Ergebnisse der subjektiven Bewertungen, Übersichtstabellen der relevanten Studien sowie die Zusammenfassung und Diskussion.

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Schlüsselwörter *Höranstrengung, Hörschwierigkeit, Signal-Rausch-Verhältnis, Pupillometrie*

Corresponding author:
Dr. Karin B. Klink
University of Oldenburg
c/o House of Hearing
Marie-Curie-Straße 2
D-26129 Oldenburg
phone 0441 / 2172-100
fax 0441 / 2172-150
Mail: karin.klink@uni-oldenburg.de

Main abbreviations in this review:
EXP=experiment
NH= normal hearing
HI= hearing impaired
SNR=signal-to-noise ratio
SRT= speech recognition threshold
fMRI = functional magnetic resonance imaging

Introduction

The hearing and understanding of speech is an integral part of human communication. Listening to speech, however, can be affected by several factors. For example, imagine two situations, a conversation in a quiet room and a conversation in a crowded café; it is possible that you will be able to understand the speech in both situations perfectly. However, the effort you will need to invest into listening in the café will most likely be higher.

In case of hearing impairment, the situation might be even more difficult: you might be able to follow the conversation in the quiet room with moderate effort; however, you might need a high effort to understand at least parts of the conversation in the café.

Such problems are indeed often reported by hearing-impaired listeners, and while these statements might be considered individual observation, also questionnaires addressing a larger number of individuals have reported similar findings in everyday life: Gatehouse and Noble (2004), for example, developed the »Speech, Spatial and Qualities of Hearing Scale« (SSQ) to investigate a range of hearing disabilities using ratings of the difficulties experienced in different situations and comparing these ratings with an independent measure of handicap and hearing impairment. The SSQ test consists of 49 questions about listening to speech, localization of sounds and different sound qualities. Three of these questions deal with the effort during listening, prompting subjects to rate the »effort of conversation«, the »need to concentrate when listening« and the »ability to ignore competing sounds« (Q14, Q15 and Q18 in newer version 5.6). Results obtained from 153 new clinic clients prior to hearing aid fitting showed not only relatively high ratings for these questions (i.e., high effort perceived in these situations), the ratings were also highly correlated with measures of hearing impairment (e.g., the level of hearing impairment in the better ear) and the obtained handicap score, indicating a good correlation between impairment (threshold) and disability (SSQ). Meis and Gabriel (2001) developed a questionnaire with several »open« and 15 »closed« questions to investigate the everyday listening effort of 100 subjects with different degrees of hearing impairment. They found that the use of a hearing aid resulted in a significantly reduced hearing effort compared to unaided listening, and that the magnitude of the perceived effort during unaided listening depended on the level of hearing impairment.

Other studies focused on a more experimental approach. Possible relationships between listening difficulty and different objective measures of room acoustics were investigated, for example, by the group of Morimoto and Sato. In their experiments, listening difficulty during listening to speech under different simulated sound fields was rated on a 4 point scale (»not«, »a little«, »fairly«, »extremely« difficult) and then plotted against several room acoustic parameters. Morimoto, Sato and Kobayashi (2004) found that there was a highly negative correlation between intelligibility and listening difficulty for Japanese words in two reverberant room conditions. The researchers proposed that both factors can be used to evaluate speech transmission performance. However, according to their data, listening difficulty should be used at high performance levels as it is more sensitive. Sato and colleagues (2008) showed that word intelligibility decreased with increasing listening difficulty. However, while intelligibility changed only by 27%, listening difficulty changed by 96%. Relationships between listening difficulty and other factors of room acoustics showed that listening difficulty and the speech transmission index were highly negatively correlated.

A schematic illustration of an assumed relation between speech intelligibility and listening effort is depicted in figure 1: Listening effort decreases (grey dashed) and speech intelligibility increases (black) with increasing signal-to-noise ratio (SNR). However, there is a range of SNRs in which the speech intelligibility is already near 100% (indicated with the vertical dashed line) but the listening effort still has not reached its minimum. At these conditions, further increases of SNR have no effect on intelligibility, but can affect listening effort significantly. This observation indicates that listening effort is an additional factor describing comprehension of speech in noisy situations and should be included in the evaluation of noisy listening conditions, especially when testing hearing aids with only small speech intelligibility differences with regard to the implemented algorithms.

Taken this aspect into account, noise reduction algorithms have been observed to have different effects on speech intelligibility and listening effort (Marzinzik and Kollmeier, 1999), as noise reduction algorithms did not increase speech intelligibility (measured at 50% SRT), but could have positive effects on perceived listening effort.

The aim of this publication is to review the literature on listening effort and also to evaluate which procedure may provide a practical way to measure listening effort, especially for evaluations of hearing aids.

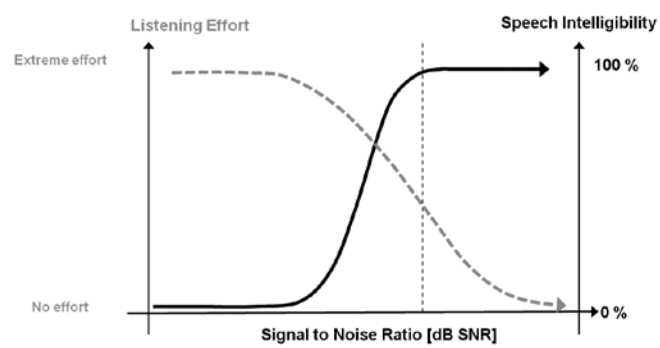


Fig. 1: Schematic illustration of the assumed relationship between speech intelligibility and listening effort.

Abb. 1: Schematische Darstellung des vermuteten Zusammenhangs zwischen Sprachverständlichkeit und Höranstrengung.

Methods

In order to find appropriate studies on listening effort, a literature research with the search engine PubMed was conducted using the key words »listening effort«, »ease of listening«, »listening comfort« and »listening difficulty« (deadline February 2012). It is important to mention that these keywords are often used to describe the effort during listening as defined above, but they could also have other - unrelated - meanings. In these cases the publications were not considered in the results.

Additionally, an existing data base was also searched using the same key words, and further publications (including miscellaneous searches in PubMed and on various other sites and also non published literature) were added into the review when they proved to be of importance to the subject studied.

The search results were then reviewed according to the relevance. Appropriate studies had to include (more or less elaborate) procedures to measure listening effort. A single question regarding listening effort was not sufficient for an inclusion into the list of key publications. Furthermore, the use of speech stimuli was mandatory. Because of a possible confusion between listening effort and other aspects of speech acquisition, studies involving children were also excluded from the analysis, as well as studies which were published before 1975. Studies fitting the criteria were then analyzed according to type of measurement, focus of study, subjects and other details.

Results

The initial search using the above listed keywords in PubMed produced the following results: 35 for »listening effort«, 14 for »ease of listening«, 19 for »listening comfort« and 16 for »listening difficulty«, although not all of these results fit the above criteria (especially the keyword »listening comfort«). A search of the preexisting data base produced no additional results which matched the criteria. Other miscellaneous searches in PubMed and on various other sites resulted in 18 further publications to be considered for the review.

After a further evaluation (especially considering a potential use in the area of audiology), the relevant publications were then divided into three main types of measurement of listening effort: measurements of *physiological reactions*, measurements of *cognitive performance* and *subjective ratings (direct scaling* of listening effort *or questionnaires)*. All in all, 54 publications about listening effort were discussed in the text. Of these publications, 11 focusing on physiological reactions, 20 focusing on cognitive performance and 15 publications focusing on subjective ratings were considered as key publications for the above mentioned research questions and were included in the tables. The tables give a short overview of the main 46 findings regarding listening effort (subjects, type of measurement, focus and outcome).

Several publications included two measures of listening effort, e.g., cognitive performance and subjective ratings; in these cases, publications were listed as belonging to the physiological or cognitive measurements.

Measurements of physiological reactions

Several studies showed that the effort applied to the understanding of speech may have an influence on physiological processes of the human body involving both autonomic body reactions (e.g., the dilation of the pupil) and changes in brain activity (e.g., measured by functional magnetic resonance imaging). Especially the dilation of the pupil has been found to be sensitive to changes in mental effort during listening. **Hyönä and colleagues** (1995) studied the pupil dilation in response to tasks of different complexity in native Finnish students during listening to different sets of Finnish or English words. The task of the subjects was either to simply acknowledge the word by saying »Yes« (»listening task«), to repeat the word (»shadowing task«) or to translate the word into another language (either from Finnish to English or vice versa; »translating task«). Half of the words in each language were easy to translate while the other half required a more difficult translation by a phrase. The results showed that pupil dilation was dependent on task complexity and was significantly larger during the translating task while being lowest during the listening task. In addition, the pupil dilation was also dependent on the translation difficulty and on the language of the presented words: Significantly larger dilations during the presentation of English words indicated a higher processing demand for listening to a non-native language compared to one's native language. These results showed that an increase in the »difficulty« of the task resulted in an increase in pupil dilation, indicating that pupil dilation was indeed dependent on the mental effort during the task (i.e., on the processing load involved). The recording of response latencies supported the data, showing significantly longer latencies during the translation task and during the presentation of the more difficult words.

Also changes in speech intelligibility were found to have an effect on pupil dilation. **Kramer and colleagues** (1997) investigated changes in the pupil dilation of normal-hearing (NH) and hearing-impaired (HI) subjects during listening to speech in noise. The results showed that pupil dilation across all participants was dependent on the SNR and therefore, the speech intelligibility: the pupil dilation in the lowest SNR condition (i.e., at a speech intelligibility of 50%) was significantly larger than in the SNR condition with a 5 dB higher speech level (see also fig. 2). Furthermore, the decrease in pupil dilation between these two conditions was significantly greater in the NH subjects compared to the HI subjects, indicating a smaller benefit of easier listening conditions (i.e., a smaller decrease in listening effort) in HI subjects. There was also a significant correlation between the SNR at the 50% intelligibility level and the decrease of dilation when the SNR was raised by 5 dB, showing that »the poorer the subject's speech reception threshold in noise, the less benefit is yielded from a more favorable listening situation« (Kramer, Kapteyn et al. 1997).

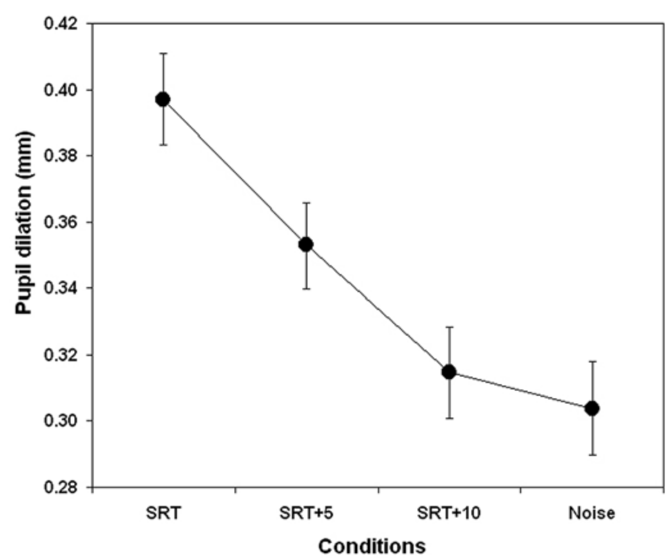


Fig. 2: Mean pupil dilation during listening to speech in noise for different signal-to-noise ratios. SRT= signal-to-noise ratio at 50% speech intelligibility (data taken from Kramer et al., 1997).

Abb. 2: Mittlere Pupilenerweiterung während des Hörens von Sprache in Hintergrundgeräuschen bei verschiedenen Signal-Rausch-Verhältnissen. SRT= Signal-Rausch-Verhältnis bei einer Sprachverständlichkeit von 50% (Daten aus Kramer et al., 1997).

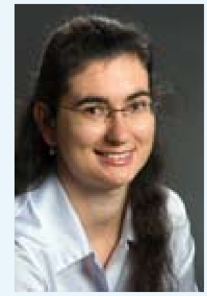
The influence of speech intelligibility on pupil dilation in young and middle-aged NH listeners and middle-aged HI listeners was investigated by **Zekveld and colleagues** (Zekveld et al., 2010; Zekveld et al., 2011). Higher SNR levels (i.e., increasing intelligibility) resulted in smaller pupil responses (relative to the baseline) in all subject groups. However, the decrease in pupil responses with increasing SNR levels was significantly larger in the NH subjects (both young and middle-aged) compared to the middle-aged HI subjects, indicating that the decline in processing load due to increasing intelligibility was affected by hearing loss but not by age. The response duration, on the other hand, was influenced by age, showing that pupil responses in young listener had significantly shorter durations compared to both middle-aged listener groups.

The effect of age on pupil dilation was also investigated by **Piquado and colleagues** (2010) in two experiments. In a first experiment, younger and older NH adults were instructed to remember and later recall lists of 4, 6 or 8 spoken digits. In a second experiment, younger and older NH adults were instructed to remember and later recall subject and object relative sentences of either 9 or 12 words in length. Both experiments showed that increases in processing demand resulted in an increase of normalized pupil size in both younger and older subjects. This increase was similar in both age groups; however, because of the older adults' more limited range in pupil dilation, these subjects had a larger normalized pupil size at the start of the experiment which therefore resulted in a larger normalized pupil size during retention. Furthermore, contrary to the younger adults, older adults exhibited no syntax-related pupil changes, probably due to their increased experience with the language and no need to invest more effort into the syntactically more difficult task.

A similar study with young and middle-aged NH subjects (**Koelewijn et al.**, 2012) focused on the effects of age, intelligibility and background noise type (stationary noise, fluctuating noise, single-talker masker) on pupil responses and subjective effort. Again, most pupil responses increased with decreasing intelligibility, but no effect of age could be seen. Subjects, however, showed larger dilations in the presence of single-talker masker compared to fluctuating or stationary noise, even if the SNR was similar (which was the case in the fluctuating noise condition).

A study by **Schulte and colleagues** (Schulte et al., 2011) investigated the effect of SNR on pupil dilation and subjective rating of listening effort in NH listeners and found that SNR significantly influenced both dilation and rating. Listening effort decreased with increasing SNR, pupil dilation however, did not always show such a clear relationship with SNR. When both measurements were obtained within a single experiment, pupil dilation and perceived effort were significantly correlated with each other, but the correlation was low (r=0.4).

A study by **Engelhardt and colleagues** (2010) investigated the effect of prosody (i.e., intonation and timing) on the dilation of the pupil. In the experiment, native English speakers were instructed to listen to syntactically ambiguous sentences containing either a prosodic break (»cooperative prosody«), or lacking the break (»conflicting prosody«). The results showed that the change in pupil diameter (the slope of the dilation) was significantly larger during conflicting prosody than during cooperative prosody. To determine whether additional (consistent or inconsistent) visual context had an effect on the processing effort, the experiment was then repeated (Experiment 2). Both experiments showed that conflicting prosody resulted in a significant increase in pupil diameter compared to cooperative prosody conditions, but that the processing effort could be affected by visual context.



Dr. Karin B. Klink is a staff member of the Medical Physics group at the Carl von Ossietzky Universität Oldenburg. After finishing her study of Biology at the University of Bielefeld she relocated in 2002 to the Oldenburg University. From 2004 till 2008 she was an associated member of the International Graduate School »Neurosensory Science and Systems« and finished her Ph.D. in 2008 in the area of animal psychoacoustics. After her Ph.D. she collaborated in several studies investigating hearing in normal-hearing and hearing-impaired human listeners at the Hörzentrum Oldenburg. Since April 2011 she is involved in coordinating projects at the Medical Physics group.

Dr. Karin B. Klink ist wissenschaftliche Mitarbeiterin in der Arbeitsgruppe Medizinische Physik der Carl von Ossietzky Universität Oldenburg. Nach ihrem Studium der Biologie an der Universität Bielefeld wechselte sie 2002 an die Carl von Ossietzky Universität Oldenburg, wo sie von 2004 bis 2008 assoziiertes Mitglied im internationalen Graduiertenkolleg »Neurosensorik« war und 2008 im Bereich der Tierpsychoakustik promovierte. Nach ihrer Promotion arbeitete sie als Honorarkraft für das Hörzentrum Oldenburg an mehreren Studien zum Hören bei Menschen mit und ohne Hörbeeinträchtigung mit. Seit April 2011 ist sie in der Arbeitsgruppe Medizinische Physik vor allem im Bereich Koordination tätig.

Aside from pupillometric measurements of processing load, listening effort was also investigated by means of functional magnetic resonance imaging (fMRI). **Peelle and colleagues** (2010) investigated the effects of scanning noise on the processing of sentences and signal-correlated noise during echoplanar imaging in NH subjects and found listening effort-related peaks of activity along left superior temporal cortex and left inferior parietal cortex. **Blackman and Hall** (2011) evaluated the use of two different scanning sequences and of active noise cancellation on the processing of sentences and narrowband noise in NH subjects, and obtained measures of perceived listening effort during the presentation. They found that for both narrowband noise and speech, activity was greatest in primary auditory cortex and adjacent regions, and that overall sound-related activity in Heschl's gyrus and in planum polare was higher with noise cancellation than without. This increase in activity might be due to a reduced listening effort, as a reduction of background noise due to active noise cancellation should make target sounds more prominent and easy to listen to.

The influence of task difficulty on other physiological parameters was investigated by **Mackersie and Cones** (2011). The researchers measured the electromyographic activity of the frontalis muscle (forehead area), skin conductance, skin temperature and heart rate and obtained subjective ratings of task effort of NH subjects during a speech recognition task with low, medium or high task demand. They found that task difficulty had significant effects on subjective ratings, electromyographic activity and skin conductance but not on skin temperature or heart rate. The authors concluded that skin conductance might be the most sensitive psychophysiological measure in both the group and individual analyses, showing a modest association with perceived effort scores (accounting for approximately 45% of the variance).

Also auditory late responses have already been used to investigate listening effort, (see, e.g., Strauss et al., 2010), however, to our knowledge none of the auditory late response studies used any speech stimuli beyond syllables, therefore, these studies were not included in the tables.

Changes in cognitive performance as indicators of listening effort

The processing of auditory (and other) stimuli takes up resources. According to a capacity model (Broadbent, 1958), the human brain possesses only a limited capacity to process information. When people are forced to perform several tasks simultaneously, the resources available need to be divided between the tasks. In cases when a primary task is very resource-consuming the resources remaining for other tasks may be insufficient and the performance on these tasks may be impaired. An established method to measure the limits of cognitive processing is the use of dual task paradigms. **Dual task paradigms** include a primary task which involves the processing of speech and a secondary task used to access listening effort which may include a reaction-time task, a short-term memory task or other measures of cognitive load (see also Anderson Gosselin and Gagné, 2010 for a review on dual-task studies of listening effort).

One of the early listening effort studies on dual-task performance was performed by **Downs and Crum** (1978) with NH listeners. The primary task involved the recognition and repetition of speech in quiet or noise while the secondary task required the subjects to press a button when a probe light was presented. Additionally, subjective ratings of perceived task difficulty were obtained. Results showed that while speech performance and perceived difficulty did not differ significantly between conditions, probe reaction time was significantly shorter during the conditions with no background noise. The level of the presented speech, on the other hand, had no significant influence on the reaction times. The results demonstrated that the presence of noise may have detrimental effects on secondary-task performance regardless of the speech level and that perceived and measured listening difficulty may not necessarily go hand in hand.

A study by **Downs** (1982) with HI subjects tested the speech discrimination performance (primary task) and the probe reaction time (secondary task) with and without hearing aid use. The results showed that speech discrimination of words in multi-talker babble was significantly better when subjects used a hearing aid compared to the unaided performance. Subjects also had a significantly shorter reaction time when using a hearing aid compared to unaided listening. Both results indicated that the use of hearing aids may improve speech discrimination while reducing listening effort.

Tun and colleagues (2009) investigated the effects of age and hearing acuity on the listening effort of younger and older NH and HI listeners in a dual task paradigm involving speech recall for related and unrelated word lists and a visual target pursuit task (tracking task) as primary and secondary tasks, respectively. Results showed that speech recall was significantly influenced by hearing acuity (NH better), age

Dr. Michael Schulte is a research assistant at the Hörzentrum Oldenburg GmbH since 2004. He is responsible for studies for the industry and works in public funded projects. He started his career in the field of audiology in 1997 at the Biomagnetism Centre of the Institute of Experimental Audiology, University Münster. In 2001 he worked for 3 month as an academic fellow in Toronto, Kanada, at the Rotman Research Institute for Neuroscience. He received his Ph.D. in 2002 in Münster. From 2002 to 2003 he worked as a Post-Doc at the F.C. Donders Centre for Cognitive Neuroimaging, Nijmegen, Netherlands.

Dr. Michael Schulte ist seit Anfang 2004 Wissenschaftlicher Mitarbeiter im Hörzentrum Oldenburg GmbH. Dort betreut er wissenschaftliche Studien im Bereich der Audiologie sowohl für öffentlich geförderte Projekte als auch für die Industrie. Seit 1997, als er am Biomagnetismuszentrum des Institutes für Experimentelle Audiologie, Universität Münster anfing, ist er im Bereich der Audiologie tätig. 2001 erfolgte ein 3-monatiger Aufenthalt in Toronto, Kanada, als Academic Fellowship am Rotman Research Institute for Neuroscience. Seine Promotion beendete er 2002 in Münster mit einem Thema zur Tonhöhenwahrnehmung. Von Mai 2002 bis Ende 2003 war er als Post-Doc am F.C. Donders Centre for Cognitive Neuroimaging, Nimwegen, Niederlande, beschäftigt.

(younger subjects better), list type (related lists better) and task type (single-task condition better than dual-task condition), with significant interactions between age and list type and between age and hearing acuity. Performance in the tracking task revealed a significant influence of age (younger subjects better) and task type (single-task condition better than dual-task conditions) and significant interaction between task type and age and/or hearing. Tun and colleagues calculated the listening effort not based on the performance in the secondary task but as the difference between single- and dual-task accuracy in the secondary tracking task, i.e. the dual-task »cost«. These costs were similar for younger subjects irrespective of their hearing acuity; for older adults, however, poor hearing acuity meant a significantly increased cost in secondary task.

Anderson Gosselin and Gagné (2011) used a sentence recognition task (primary task) and a tactile pattern recognition task (secondary task) to investigate the effects of age on the listening effort of younger and older NH subjects during speech presented in speech-shaped noise. Accuracy and response times in both tasks and subjective ratings of listening effort were investigated in two conditions: an equated level condition (constant noise level) and an equated performance condition (individually increased noise level to target a performance of at least 80% correct responses). Both absolute changes in single-/dual-task performance and relative dual task costs (i.e., absolute changes divided by the subject's individual single task performance) were analyzed. Results showed that in the equated level condition, absolute accuracy scores and response times in both tasks were significantly worse for older adults than for younger adults. Relative dual task costs, however, were unaffected by age in the speech task but were significantly larger in older adults in the tactile task. In the equated performance condition, relative measures of task accuracy revealed a similar outcome, showing no age effects in the speech task and significant age effects in the tactile task. Response time measurements showed no age effect when relative dual-task costs were compared, but older subjects had significantly longer absolute response times than younger subjects. A comparison between the equated level and equated performance condition for the subgroup of older adults which required a change in noise level showed that in the tactile task, the reduction of noise level in the equated performance condition lead to significantly reduced relative response times, indicating a reduced listening effort due to noise reduction. Furthermore, audiovisual presentation of the stimuli could have a negative effect on accuracy scores in both tasks (see Gosselin and Gagné, 2011 for details).

Rakerd and colleagues (1996) tested the influence of listening conditions on the memory performance in a dual-task paradigm. They instructed NH and HI subjects to memorize visually presented digit lists (secondary task) while listening to either speech or speech-shaped noise (primary task). Experiment 1 focused on the effects of hearing impairment, experiment 2 focused on the effect of age and hearing impairment. In both experiments, memory performance in the condition with speech was significantly reduced compared to the performance in the condition with speech-shaped noise. Furthermore, hearing impairment resulted in a significantly larger decrease in performance than unimpaired hearing in both experiments.

Feuerstein (1992) investigated the effects of monaural and binaural hearing on listening effort in NH subjects. He used a word recognition task (primary task) and a probe light reaction time task (secondary task) to obtain measures of speech performance, reaction time and ease of listening ratings in binaural and monaural listening conditions. Speech was presented from one loudspeaker at -65° while multi-talker babble noise was presented from a second loudspeaker at +65°. Presentation was either binaural (no ear occluded), monaural-near (MN; with the un-occluded ear oriented towards the speech and the other ear occluded using an ear plug) or monaural-far (MF; with the un-occluded ear oriented towards the noise). Results showed that speech performance, probe reaction times and perceived ease of listening all significantly depended on the listening condition. Both the binaural condition and the MN condition were always significantly better than the MF condition while the MN condition was often significantly worse than the binaural condition (except in reaction time measurements). This indicated that, when speech is presented to the side of the impaired ear, monaural listening always resulted in an increase in listening effort.

Fraser and colleagues (2010) used a speech recognition task (primary task) and a tactile pattern recognition task (secondary task) to investigate the influence of modality on listening effort for speech in noise with NH subjects. Generally, performance and reaction times in both tasks were worse when the tasks were presented in a dual-task condition compared to a single-task condition, indicating that the dual-task condition required more cognitive effort. A significant influence of modality was seen only during the speech performance - as performance in the audiovisual modality was significantly greater than in the audio-only modality – but there was no change in the cognitive effort due to modality. Perceived effort in the speech task, however, was rated to be less in the audiovisual modality compared to the audio-only modality. When the noise level in the audiovisual modality was increased to generate equal performance in both modalities (experiment 2), performance and reaction times in the (secondary) tactile task got significantly better in the audio-only condition while perceived listening effort showed no effects of modality.

Rönnberg and colleagues (2011) investigated the effects of different memory load levels on performance and reaction times in a dual-task paradigm involving a word recognition task and a subsequent memory test including measurements of accuracy and reaction time. After each memory test, perceived listening effort was rated on a 10-point scale. Results showed that increasing the memory load level resulted in reduced accuracy and increased reaction time, although reaction time only increase between the medium and high level. Perceived listening effort, on the other hand, was unaffected by the memory load level, probably because all stimuli were presented at the same SNR.

Sarampalis and colleagues (2009) investigated the influence of a noise reduction algorithm on speech perception of NH listeners in quiet or babble noise. In a first experiment, a speech discrimination task with high- and no-context words was used as a primary task while the secondary task was a memory task (recall of last word). Results revealed that for both processed and unprocessed speech, primary and secondary task performance was better with high-context words compared to no-context words, showing an effect of context on intelligibility and recall. Furthermore, there was a significant interaction between SNR and processing:

Markus Meis, PhD, is Head of the department for Market and Effects Research at Hörzentrum Oldenburg GmbH, and is part-time lecturer in Assitive Technologies at the Jadehochschule Oldenburg (University of Applied Sciences). He received his Ph.D. in medical psychology from Ludwig Maximilians University in Munich in 1997, and was a postdoctoral fellow at the Oldenburg Graduate School of Psychoacoustics from 1997 to 1999. He is coordinator of publicly financed projects, such as Health Services Research in the domain of Audiology, Ambient Assisted Living (AAL), and noise effects. Furthermore, he coordinates projects in the realm of industrial contract research, especially hearing aid industry, regarding the topics audiology, usability, room acoustics, market research, psychological acoustics, as well as sound evaluation.

Dr. Markus Meis ist Bereichsleiter für Markt- und Wirkungsforschung der Hörzentrum Oldenburg GmbH und Lehrbeauftragter für assistive Technologien an der Jadehochschule Oldenburg. Er promovierte 1997 im Bereich der Medizinischen Psychologie an der Ludwig-Maximilians-Universität in München und war von 1997 bis 1999 als PostDoc im Graduiertenkolleg Psychoakustik Oldenburg tätig. Markus Meis koordiniert Projekte der öffentlichen Forschung, wie Versorgungsforschung im Bereich der Audiologie, Ambient Assisted Living (AAL) und Lärmwirkung. Darüber hinaus leitet er Projekte der industriellen Auftragsforschung zu den Themengebieten Audiologie, Usability, Raumakustik, Markt- und Meinungsforschung, Psychologische Akustik und Klangbewertung.

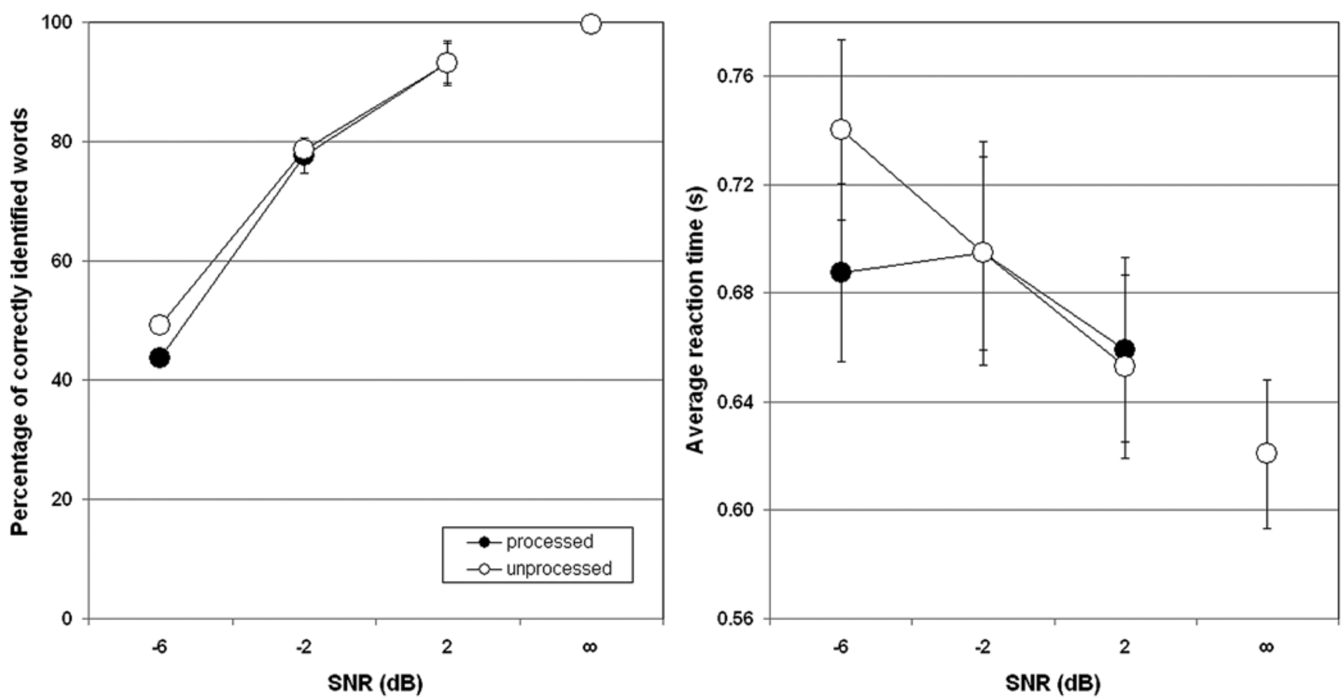


Fig 3: Effects of SNR and processing (noise reduction algorithm) on mean speech intelligibility performance (left) and average reaction time (right) in a dual-task paradigm (data taken from Sarampalis et al., 2009; experiment 2).

Abb. 3: Einfluss des Signal-Rausch-Verhältnisses (SNR) und der Verarbeitung (Störgeräuschunterdrückungsalgorithmus) auf die mittlere Sprachverständlichkeit (links) und die mittleren Reaktionszeiten (rechts) in einem »dual-task«-Paradigma (Daten aus Sarampalis et al., 2009, Experiment 2).

At a SNR of -2, speech discrimination for high- and no-context words was significantly better without noise reduction, recall for high-context words, on the other hand, was significantly better with noise reduction. In a second experiment, a speech discrimination task and a visual digit discrimination task were used as primary and secondary tasks, respectively, with secondary task reaction times used as a measure of listening effort. Results showed that both speech performance and reaction times showed significant effects of SNR but were unaffected by the processing. Speech performance worsened and reaction times generally increased with decreasing SNRs (see also fig. 3). Only at the lowest SNR of -6 dB reaction times in the processed condition were significantly shorter than in the unprocessed condition. Results from both experiments indicated that noise reduction algorithms might have positive effects on listening effort but did not significantly increase the intelligibility.

Besides dual-task experiments, also experiments involving a **single task** have been used to measure listening effort. This single task was similar to the primary task of the dual-task paradigm, however, instead of a secondary task, the reaction time in the primary task was used as a secondary measure. **Gatehouse and Gordon** (1990) used a single task to obtain performance scores and reaction times for identification and recall of single words and sentences in quiet and speech-shaped noise for HI subjects. The aim was to determine the sensitivity of both measures for HI subjects with and without the use of a hearing aid. Results showed that both performance and reaction times during speech presentation were significantly better when subjects used the hearing aid compared to unaided hearing. The change in reaction times seemed to be higher than the change in performance, and significant decreases in reaction time were also found in conditions where performance due to hearing aid use was found to be unchanged. This indicates that hearing aid use may lead to both an increase in intelligibility and to a – even higher - reduction of listening effort.

Two other single task paradigms to measure listening effort were established by **Huckvale and colleagues**: the typometer and the proofometer. In the **typometer** experiment (Huckvale and Leak, 2009; Huckvale and Frasi, 2010), NH subjects were asked to listen to digits presented in quiet and noise (babble and car noise; either unprocessed or processed using a noise reduction algorithm) and to type these quickly into a computer program. Results showed that while intelligibility remained unchanged, reaction times were significantly influenced by background condition, with a significant interaction between both factors. In all noise conditions, reaction times were significantly increased compared to the quiet condition, but no differences between noise types or between the processed and unprocessed condition were found. In the **proofometer** experiment (Huckvale and Frasi, 2010), subjects were asked to listen to speech in quiet and unprocessed and processed noise (multi-speaker babble and car noise; w/o noise reduction algorithm processing) and to correct errors in transcripts of the speech which were simultaneously presented on a computer screen. Results revealed that performance in noise was significantly reduced compared to the quiet condition but there were no significant differences between conditions with and without processing. The results indicated that in both experiments, listening effort was significantly affected by noise but not by a noise reduction algorithm.

Drgas and Blaszak (2009) used a modified single task paradigm to investigate the effects of parameter changes in vocoded speech on intelligibility, listening effort and subjective difficulty of NH listeners. The researchers changed the number of bands, the frequency modulation cutoff (FMC) and the reverberation time while subjects listened to nonsense words and repeated the words into a microphone (reaction time measurement) and wrote them down on a keyboard (intelligibility measurement). Results showed that speech intelligibility, reaction times and perceived listening difficulty generally improved with increasing number of bands, with increasing FMC and with decreasing reverberation time.

The effort invested into listening to speech under difficult conditions can also have effects on the working memory, for example on serial recall or on the performance of complex tasks. **Surprenant** (1999) investigated the effects of noise on working memory of NH subjects in a syllable identification and recall test in quiet and broad-band noise. Performance in syllable identification was significantly affected by the background condition, showing significantly decreased performance in noise conditions compared to the quiet condition. Performance in syllable recall was significantly affected by the noise condition (reduced performance with increasing noise level) and the serial position of the syllables, with an interaction between both factors.

Hällgren and colleagues (2005) focused on the role of hearing aids and modality (audio-only, audiovisual) on speech understanding and cognitive performance of younger and older HI subjects in quiet, Hagerman noise or (background) speech. Results showed that speech understanding in quiet and noise was significantly increased during listening with a hearing aid, with the performance being significantly better in speech compared to Hagermann noise. Cognitive performance in the SVIPS (»Speech and Visual Information Processing System«; tests involving semantic and lexical decision making and name matching) test battery revealed significant effects of age (younger better), modality (audiovisual better) and background condition (best in quiet, worst in speech). Reaction times in the SVIPS test were significantly influenced by modality (longer in audiovisual modality) and background condition but not by age or hearing aid use. Perceived effort, measured with a rating scale from 0 to 10, could be influenced by different factors depending on the cognitive test used. During the Hagerman speech test listening effort was dependent on the background condition but not on modality, hearing aid use or subject's age. During the SVIPS test, however, listening effort was dependent on background condition (best in quiet, worst in speech), modality (lower in audiovisual modality) and hearing aid use (lower with aid) but not on subject's age, and there were significant interactions between age and modality, and between other factors. **Larsby and colleages** (Larsby et al., 2005) focused on speech understanding and cognitive performance of younger and older NH and HI subjects in three modalities (visual, audio-only and audiovisual) and four background conditions (quiet, Hagerman noise, ICRA noise or speech). Results of the SVIPS test in the audio-only and audiovisual modalities showed that in the presence of speech or noise, performance and reaction times became significantly worse. There was also an interaction between background condition and noise, leading to decreased performance in the auditory modality and increased reaction times in the audiovisual modality in some of the tests. In the speech and noise conditions, accuracy and reaction times were affected by age, hearing acuity, and modality. Perceived listening effort was significantly influenced by hearing status (higher for HI), modality (highest in audio-only, lowest in visual modality) and noise condition (lower in quiet), but not age.

Picou, Ricketts and Hornsby (2011) investigated the effects of visual cues on working memory and perceived listening effort in NH subjects. They found that four-talker babble noise reduced recall performance significantly and led to higher perceived effort ratings. The addition of visual cues (i.e., the difference between the audiovisual and the audio-only condition), on the other hand, had no effect on recall or perceived effort.

Klatte and colleagues (2007) focused on the effects of background sound and reverberations on the retaining and processing of speech information. Adult listeners (results from children were not considered in this review) were asked to either remember the sequence of seven words, or to follow complex spoken instructions. Both tasks were performed either in quiet, background speech or classroom noise without speech while the reverberation time in the room was either short (»favourable« room condition, T30=0.47 s) or long (»adverse« room condition, T30=1.1 s). Results revealed that memory performance in the favourable room condition – compared to the quiet condition – was significantly impaired by the background speech but not by the classroom noise. When the performance in both reverberation conditions was compared, the effects of room condition and background noise were significant, showing that adverse room conditions amplified the effects of noise, resulting in significant impairments in performance in background speech and classroom noise. Complex tasks were not significantly impaired by background speech or classroom noise in the favorable room condition, but the adverse room condition had a significant negative effect on the performance in both noise backgrounds. These experiments showed that even in the favorable room condition, background speech resulted in increased listening effort. In the adverse room conditions, the effects of background noise were generally increased, impairing performance also in the »effortless« classroom noise condition while impairing performance in background speech even further.

– To be continued in issue 3/2012–
– Fortsetzung in Heft 3/2012 –

NEU: PUBLIKATIONSPREIS

DGA-Publikationspreis

Anlässlich der Jahrestagung der Deutschen Gesellschaft für Audiologie (DGA) im März 2012 in Erlangen hat das Präsidium der DGA beschlossen, einen Publikationspreis für den besten Originalbeitrag der Zeitschrift für Audiologie auszuschreiben. Der neugeschaffene DGA-Publikationspreis ist mit 300,- € dotiert und wird jeweils anlässlich der DGA-Jahrestagung für den besten Originalartikel vergeben, der im vorhergehenden Kalenderjahr in der Zeitschrift für Audiologie erschienen ist. Über die Vergabe des Preises entscheidet das Editorial Board der Zeitschrift für Audiologie. Es werden alle im Vorjahr publizierten Originalarbeiten automatisch in das Auswahlverfahren einbezogen, so dass es keiner formalen Bewerbung um den Publikationspreis bedarf. Damit sind alle potentiellen Autorinnen und Autoren herzlich eingeladen, sich durch Einreichung von Originalmanuskripten bei der Zeitschrift für Audiologie für die Verleihung des DGA-Publikationspreises zu qualifizieren.