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Author contact	annelies.devesse@kuleuven.be

Age Affects Speech Understanding and Multitask Costs

Annelies Devesse, Jan Wouters and Astrid van Wieringen

KU Leuven – University of Leuven, Department of Neurosciences, ExpORL, Herestraat 49 bus 721, B-3000 Leuven, Belgium (the same for each author)

Address correspondence to Annelies Devesse,
KU Leuven Department of Neurosciences, ExpORL
Herestraat 49 bus 721, B-3000 Leuven (Belgium)
Fax +32 16 330486 / Phone +32 16 32 14 68
E-mail: annelies.devesse@kuleuven.be

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Abstract

Objectives: We examined the effect of age on speech understanding and multitask costs in the ecologically relevant ‘Audio-Visual True-to-Life Assessment of Auditory Rehabilitation’-paradigm (AVATAR).

Design: Twenty-nine normal hearing middle-aged adults completed AVATAR, which combines an auditory-visual speech-in-noise task with three secondary tasks on auditory localization or visual short-term memory in different dual-, triple- and quadruple-task combinations. Performance decrements on the secondary tasks were considered to reflect the cognitive resources allocated during listening. Self-reported hearing difficulties were administered via a questionnaire. Results were compared with scores of 35 young normal hearing adults.

Results: Middle-aged adults performed consistently worse than young adults on speech understanding and, in the triple- and quadruple-task combinations only, on secondary task performance. Furthermore, middle-agers reported higher levels of daily listening concentration and more difficulties with speech understanding.

Conclusions: This study demonstrated the adverse effect of age on speech-in-noise understanding and the amount of allocated cognitive resources during challenging listening situations realized in AVATAR.

Introduction

Auditory and cognitive functions interact significantly during everyday listening (Arlinger 2009). In demanding listening situations, for instance, cognitive processing resources are needed to overcome listening obstacles. If a listener deliberately allocates these resources, listening is considered effortful (Pichora-Fuller et al. 2016). Since both auditory and cognitive abilities decline with age (Tremblay et al. 2016), it is not surprising that older adults experience more listening effort than young adults (Ward et al. 2017), even when they have clinically normal hearing thresholds (Gosslin & Gagné, 2011; Desjardins & Doherty, 2013).

To understand hearing difficulties across the lifespan, sensitive ecologically valid measures are needed that mimic the demands of daily listening environments. Behavioral dual-task paradigms are good candidates for this, as they simulate multitasking, which is an important aspect of daily life, and provide a proxy of the amount of effort people exert during listening (for a review, see Gagné et al. 2017). Dual-task paradigms assume that the amount of cognitive resources people can allocate during listening is limited in capacity and shared among concurrent tasks (Kahneman 1973). As such, performance decrements on a secondary task reflect the increased amount of allocated resources to the main task and thus the effort spent.

In this study, we investigated how age affects speech understanding and cognitive effort during multitasking in the ‘Audio-Visual True-to-life Assessment of Auditory Rehabilitation’-paradigm (AVATAR) (Devesse et al. 2019). Typically, the effect of age on effort is studied in adults over 60 years of age, but studies including middle-aged adults showed that hearing difficulties and listening effort already start to increase from the fourth decade of life onwards (Degeest et al. 2015; Helfer et al. 2017). Therefore, we compared outcome scores of middle-aged normal hearing adults with scores of young adults tested previously with AVATAR. In contrast to classic dual-task paradigms, AVATAR combines a speech-in-noise task with not

one but three secondary tasks in an audiovisual environment, to better mimic everyday demands. We hypothesized that secondary task performance of middle-aged adults would decrease with increasing task complexity. Second, we expected that their speech understanding and secondary task performance would be worse than young adults. Finally, we administered a questionnaire assessing self-reported hearing difficulties and hypothesized that difficulties would increase with age.

Materials and Methods

Participants

Twenty-nine adults aged 45 to 60 years (Mean = 52.5 years, SD = 3.7 years) participated. All were Dutch speaking, reported good vision and had bilateral hearing thresholds no higher than 25 dB HL from 250 to 4000 Hz, measured through TDH-39 earphones and a Madsen OB922 audiometer in a sound-attenuating room. All participants passed the Montreal Cognitive Assessment with a minimum score of 26, indicating normal cognitive function. The study was approved by the Medical Ethical Committee of the University Hospitals KU Leuven (approval number B322201526677) and every participant gave written informed consent.

Multitasking

Speech understanding and secondary task performance were assessed using the AVATAR-paradigm, as described in Devesse et al. (2019). The set-up consisted of a computer, RME Fireface UCX soundcard, short-throw beamer (Optoma EH200ST), acoustically transparent screen (1.73x3m, Project Tension Elpro Concept (RF)) and five FOSTEX 6301B3 loudspeakers positioned at ± 45 , ± 22.5 or 0-degree angle relative to the listener on a straight line behind the screen, 1.20m above the ground. A sixth speaker was placed at the zenith, 0.80 m above the listener's head. All stimuli were calibrated at the participant's head position.

One main task, a speech-in-noise (SPIN) task and three secondary tasks covering auditory localization (LOC), detection of the direction of movement of dynamic sounds (DYN) and visual short-term memory (VIS) were conducted in a virtual restaurant scenario. Tasks were administered both individually and in all possible task combinations (Table 1). Every condition was tested twice and the order of conditions was randomized across individuals.

SPIN consisted of multitalker babble noise (Francart et al. 2011) and meaningful sentences of the Leuven Intelligibility Sentences test (van Wieringen & Wouters, 2008). Noise was presented at a fixed level of 60 dB A through the zenith speaker. Sentences were uttered at 0-degree angle by a virtual human, providing both auditory and visual information (Devesse et al. 2018). The speech level was adjusted adaptively in a 1-up 1-down manner, with a step size of 2 dB. Sentences were correct if all key words were repeated correctly. The speech reception threshold was calculated as the average of the last five sentences plus a fictive 11th sentence (van Wieringen & Wouters, 2008). In LOC, listeners had to localize a 1 sec broadband phone sound at ± 45 , ± 22.5 or 0-degree angle, whereas in DYN, they had to report the direction of a 3 sec broadband fly sound passing by (from right to left or vice versa). Stimuli of both LOC and DYN were presented through the five speakers in the horizontal field at 60 dB A. VIS consisted of a visual one-back task, in which participants had to remember a visual two-digit number that changed every 10 seconds (single task) or with every new sentence from the main task (task combinations). During task combinations, 10 trials with a unique SPIN sentence were combined with different LOC-, DYN- and/or VIS-stimuli (Table 1). More specifically, from the second trial on, five LOC-, four DYN- and/or nine VIS-stimuli were distributed randomly over the nine remaining trials, but only if the specific task combination asked for it. For example, no DYN- or VIS-stimuli were added to the SPIN+LOC combination. Each trial contained, at most, one stimulus per task. All LOC- and DYN-stimuli were presented at the start of a trial, before the sentence. VIS-stimuli changed right before or during the first 2 secs of each sentence, were

projected at chest-height of the middle virtual human and remained visible during the entire trial. Participants were instructed to always give priority to the speech-in-noise task and to answer on the secondary tasks after they repeated the sentence.

Self-report

Self-reported hearing abilities were administered through the short version of the pencil and paper questionnaire Speech, Spatial and Qualities of Hearing scale (SSQ12) (Noble et al. 2013). Twelve questions were grouped into three different subscales, covering speech understanding, localization abilities and sound quality. One item of the quality subscale questioned the level of concentration during listening. Participants had to indicate their answer on a 10-point visual analogue scale (0 = bad hearing/extreme concentration, 10 = perfect hearing/no concentration).

Data analysis

Statistical analysis was performed using R software. Test and retest scores of each AVATAR condition were averaged before analysis. Repeated outcome measures on AVATAR and SSQ12 were compared with results of a group of 35 young normal hearing adults aged 18 to 30 years (Devesse et al. 2019) by means of mixed linear models and post-hoc Tukey analysis, corrected for multiple comparisons. Although pure tone averages (PTA; 0.5, 1, 2 and 4 kHz) were clinically normal for all participants, they differed between young ($Mean=4.64$ dB HL, $SE=0.60$ dB) and middle-aged adults ($Mean=9.55$, dB HL $SE=0.65$ dB), $t(60)=-5.50$, $p<0.001$, $r=0.58$ (Figure 1). To control for the group difference in PTA and additionally for a significant group difference in thresholds at 8 kHz ($p<0.001$), we included *hearing level* (i.e. average of 0.5, 1, 2, 4 and 8 kHz) as an explanatory variable in each model next to main and interaction effects of the variables of interest (*group*, *task combination* or *SSQ12-question*).

Results

Speech understanding and multitask costs

Speech reception thresholds were higher for adults with higher hearing thresholds, $\chi^2(1)=4.57$, $p<0.05$, and for middle-aged adults compared to young adults, $\chi^2(1)=4.06$, $p<0.05$, as shown in Figure 2A. The main effect of task combination was not significant, $\chi^2(7)=4.82$, $p=0.68$, nor was the interaction between group and task combination, $\chi^2(7)=4.68$, $p=0.70$.

Performance decrements were found on the secondary VIS- and LOC-tasks, but not on the DYN-task. First, we found a significant main effect of hearing level for the VIS-task, $\chi^2(1)=12.99$, $p<0.001$, revealing that individuals with higher hearing thresholds had overall lower VIS-scores. The interaction between group and task combination was also significant, $\chi^2(4)=24.08$, $p<0.001$ (Fig. 2B); a post-hoc Tukey test showed that middle-aged adults had lower VIS-performance on all task combinations compared to baseline performance ($p<0.001$) and on all triple- and quadruple-conditions compared to dual-task performance ($p<0.001$). Compared to young adults, middle-aged adults scored significantly lower on triple- and quadruple-task combinations ($p<0.05$), but not on the baseline ($p=0.74$) or dual-task condition ($p=0.32$). Second, results showed no effect of hearing level on LOC-performance, $\chi^2(1)=0.33$, $p=0.56$, but did reveal a significant interaction effect between group and task combination, $\chi^2(4)=17.67$, $p<0.01$ (Fig. 2C). Middle-agers performed significantly worse on the quadruple-condition compared to baseline ($p<0.001$), dual-task ($p<0.001$) and triple SPIN+LOC+DYN-performance ($p<0.05$), as well as on the triple SPIN+LOC+VIS-condition compared to baseline performance ($p<0.001$). Compared to young adults, middle-agers scored significantly lower on the quadruple-task combination only ($p<0.05$). Finally, no effect of group or task combination was observed for DYN-performance, as both young and middle-aged adults obtained a median score of 1.00 on every DYN-task ($SD's<0.05$).

Self-report

As for self-report, scores on the SSQ12-questionnaire were affected by hearing level, $\chi^2(1)=7.94$, $p<0.01$, such that individuals with higher hearing thresholds scored overall worse on the SSQ12-questions. A significant interaction effect between group and question, $\chi^2(11)=34.28$, $p<0.001$ revealed that middle-agers rated their hearing significantly lower on questions 2 ($p<0.001$) and 5 ($p<0.05$) of the speech subscale, as well as on the single question considering concentration during listening ($p<0.05$) (Fig. 2D).

Discussion

This study investigated the effect of age on both speech understanding and secondary task performance during listening, by means of an ecologically relevant speech-in-noise paradigm AVATAR.

First, speech-in-noise understanding abilities of middle-aged adults did not depend on task difficulty. This was in line with results of young normal hearing adults tested previously with AVATAR (Devesse et al. 2019) and with other dual-task paradigms (Gagné et al. 2017). Overall, speech understanding was significantly worse for middle-aged adults compared to young adults, measured both behaviourally and via self-report, even after controlling for group differences in PTA and high frequency hearing thresholds. This confirmed previous research on the adverse effect of age on speech perception (Helfer et al. 2017).

Despite stable speech understanding levels, performance on two out of three secondary tasks decreased with increasing task complexity. In line with the theory of a shared, limited capacity of processing resources (Kahneman 1973), these secondary task costs suggested that when more secondary tasks were added, listeners allocated an increased amount of resources to achieve the same level of listening performance as in less demanding situations, leaving less resources

available for the VIS- and LOC-task. Performance decrements were significantly larger for middle-aged compared to young adults in the triple- and quadruple-conditions, suggesting that middle-agers experienced greater downstream effects on secondary task performance with a higher number of concurrent tasks. Interestingly, including more than one secondary task thus seemed to increase the sensitivity of detecting group differences in multitask costs. Future research should clarify whether group differences arose because middle-aged adults had 1) worse cognitive abilities than young adults or 2) the same cognitive abilities, but allocated their cognitive resources differently to compensate for reduced hearing abilities (Li et al. 2005). Overall, our results replicated previous findings that the amount of allocated resources during challenging listening situations increased with advancing age, measured both behaviourally and via self-report (Gosselin & Gagné, 2011; Desjardins & Doherty, 2013; Degeest et al., 2015). Results on the SSQ12 supported these findings, as middle-agers reported higher levels of concentration during everyday listening, even when group differences in hearing thresholds were controlled for.

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References

- Arlinger, S., Lunner, T., Lyxell, B., & Kathleen Pichora-Fuller, M. (2009). The emergence of cognitive hearing science. *Scand J Psychol*, 50(5), 371-384.
- Degeest, S., Keppler, H., Corthals, P. (2015). The effect of age on listening effort. *J Speech Lang Hear Res*, 58, 1592–1600.
- Desjardins, J. L., & Doherty, K. A. (2013). Age-related changes in listening effort for various types of masker noises. *Ear Hear*, 34(3), 261-272.
- Devesse, A., Dudek, A., van Wieringen, A., et al. (2018). Speech intelligibility of virtual humans. *Int J Audiol*, 57(12), 908-916.
- Devesse, A., van Wieringen, A. Wouters, J. (2019) AVATAR assesses speech understanding and multitask costs in ecologically relevant listening situations. *Ear Hear*, XX, accessed online July 25, 2019, doi 10.1097/AUD.0000000000000778.
- Francart, T., van Wieringen, A., Wouters, J. (2011). Comparison of fluctuating maskers for speech recognition tests. *Int J Audiol*, 50(1), 2-13.
- Gagné, J.-P., Besser, J., Lemke, U. (2017). Behavioral assessment of listening effort using a dual-task paradigm: A review. *Trends Hear*, 21, 1-25.
- Gosselin, P. A., & Gagné, J.-P. (2011). Older adults expend more listening effort than young adults recognizing audiovisual speech in noise. *Int J Audiol*, 50(11), 786-792.
- Helfer, K. S., Merchant, G. R., Wasiuk, P. A. (2017). Age-related changes in objective and subjective speech perception in complex listening environments. *J Speech Lang Hear Res*, 60, 3009–3018.
- Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs, NJ: Prentice-Hall.

- 201 Li, K. Z. H., Krampe, R. Th., & Bondar, A. (2005). An ecological approach to studying aging
202 and dual-task performance. In R. W. Engle, G. Sedek, U. von Hecker, et al. (Eds.), *Cognitive*
203 *Limitations in Aging and Psychopathology* (pp. 190–218). Cambridge: Cambridge University
204 Press.
- 205 Pichora-Fuller, M. K., Kramer, S. E., Eckert, et al. (2016). Hearing impairment and cognitive
206 energy: The framework for understanding effortful listening (FUEL). *Ear Hear*, 37, 5S-27S.
- 207 Tremblay, K. L., & Backer, K. C. (2016). Listening and learning: Cognitive contributions to
208 the rehabilitation of older adults with and without audiometrically defined hearing loss. *Ear*
209 *Hear*, 37(Suppl 1), 155S.
- 210 van Wieringen, A., & Wouters, J. (2008). LIST and LINT: Sentences and numbers for
211 quantifying speech understanding in severely impaired listeners for Flanders and the
212 Netherlands. *Int J Audiol*, 47(6), 348-355.
- 213 Ward, K. M., Shen, J., Souza, P. E., et al. (2017). Age-related differences in listening effort
214 during degraded speech recognition. *Ear Hear*, 38(1), 74.

Figures

Figure 1. Hearing thresholds of 29 middle-aged adults compared to a control group of 35 young adults. **A**, Average hearing thresholds for all individual frequencies, error bars represent 95% confidence interval on the mean. **B**, Pure tone averages (PTA) (average of 0.5, 1, 2 and 4 kHz) differed significantly between young and middle-aged adults.

Figure 2. Results of 29 middle-aged adults compared with results of 35 young adults tested in Devesse et al. (2019). **A**, Performance on the main speech-in-noise (SPIN)-task did not depend on task complexity (SRT = speech reception threshold). Results on the SPIN-task were averaged across conditions with the same amount of tasks. **B**, Performance on the secondary visual short-term memory (VIS)-task decreased with increasing task complexity. **C**, Localization performance on the secondary auditory localization (LOC)-task was stable across conditions. **D**, Two questions from the speech subscale of the Speech, Spatial and Qualities of Hearing scale (SSQ12) (questions 2 and 5), as well as the single question on concentration during listening (question 12), differed significantly between young and middle-aged adults.

229

Abbreviations

230 AVATAR = Audio-Visual True-to-Life Assessment of Auditory Rehabilitation

231 DYN = dynamic sound detection task of AVATAR

232 LOC = localization task of AVATAR

233 PTA = pure tone average

234 SPIN = speech-in-noise task of AVATAR

235 SRT = speech reception threshold

236 SSQ12 = short version of the Speech, Spatial, and Qualities of Hearing Scale

237 VIS = visual memory task of AVATAR

Figure 1

Figure 2

Table 1: Overview of all task combinations and outcome measures of the behavioral multitasking paradigm. Per condition, one outcome measure was calculated for each task (adapted from Devesse et al. 2019).

	No. of tasks	Name of condition	Trials + content	Task	Outcome measure
Single task	1 task	SPIN	10 trials: 10 sentences	Repeat sentence	SRT (dB SNR)
		LOC	5 trials: 5 phone signals, every location once	Report location	RMS error (°)
		DYN	2 trials: 2 fly signals, every direction once	Report direction	% correct
		VIS	10 trials: 10 numbers	Report previous number (1-back)	% correct
Dual-task	2 tasks	SPIN+LOC SPIN+DYN SPIN+VIS	All conditions: 10 trials	Repeat sentence	SRT (dB SNR), RMS error (°), % correct DYN, % correct VIS
Triple-task	3 tasks	SPIN+LOC+DYN	10 sentences + from 2 nd trial on:	+ if present: report location (LOC) and/or direction (DYN)	
		SPIN+LOC+VIS	5 phones (every location once),	+ if present and asked for:	
		SPIN+DYN+VIS	4 flies (every direction twice),	report previous number (VIS)	
Quadruple-task	4 tasks	SPIN+LOC+DYN+VIS	9 numbers		

SPIN refers to the main speech-in-noise task and LOC (localization), DYN (dynamic sound) and VIS (visual memory) to the secondary tasks.