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Comprehension of a Novel Accent by Young and Older Listeners

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The authors investigated perceptual learning of a novel accent in young and older listeners through measuring speech reception thresholds (SRTs) using speech materials spoken in a novel—unfamiliar—accent. Younger and older listeners adapted to this accent, but older listeners showed poorer comprehension of the accent. Furthermore, perceptual learning differed across groups: The older listeners stopped learning after the first block, whereas younger listeners showed further improvement with longer exposure. Among the older participants, hearing acuity predicted the SRT as well as the effect of the novel accent on SRT. Finally, a measure of executive function predicted the impact of accent on SRT.

Keywords: speech comprehension, accented speech, aging, hearing, cognitive factors

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Listeners can quickly learn to comprehend distorted or unfamiliar speech streams, such as noise-vocoded (Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995), time-compressed (Golomb, Peelle, & Wingfield, 2007; Pallier, Sebastián-Gallés, Dupoux, Christophe, & Mehler, 1998), and foreign-accented speech (Clarke & Garrett, 2004), to name a few. This ability to adapt appears to remain stable throughout the life span (Golomb et al., 2007; Peelle & Wingfield, 2005). However, older listeners have been found to perform less well at understanding time-compressed speech (i.e., speech that has been artificially shortened) than do younger listeners (Janse, 2009; Peelle & Wingfield, 2005; Wingfield, Tun, Koh, & Rosen, 1999). This has been linked to age-related hearing loss in older listeners (Gordon-Salant & Fitzgibbons, 1993, 2001) and may also be due to aging of cognitive abilities (Salthouse, 2000). Age-related changes have been shown in perceptual adaptation to speaker characteristics and amplitude fluctuations (Sommers, 1997), even when the older adults had normal hearing.

We are interested in how older listeners adapt to a naturalistic distortion (Adank, van Hout, & Van de Velde, 2007; Best, McRoberts, & Goodell, 2001; Clopper, Pisoni, & de Jong, 2005; Flege, 1991) of the speech signal, that is, speaking with a foreign or regional accent. Accented speech represents variation that (older) listeners encounter every day and that is processed slower and less efficiently than is native speech (Adank, Evans, Stuart-Smith, & Scott, 2009; Floccia, Goslin, Girard, & Konopczynski, 2006; Munro & Derwing, 1995; Rogers, Dalby, & Nishi, 2004), but also represents a distortion that listeners can quickly adapt to (Clarke & Garrett, 2004).

We investigated first whether older and younger adults' listening performance is equally affected by accented speech. Second, we determined whether older and younger listeners show comparable perceptual learning of accented speech. Third, we aimed to obtain more insight into the mechanisms underlying the perceptual learning process by relating older listeners' learning and comprehension of the accented speech to their hearing acuity and to measures of cognitive function.

Relative comprehension performance of young and older listeners was established through an adaptive staircase procedure involving comprehension of accented sentences in noise. If, after exposure to the accent, listeners could maintain the same level of task performance while more noise was added to the signal, then this was assumed to signify learning. Individual speech-in-noise performance was related to a measure of hearing acuity (pure-tone audiometry) and to two cognitive measures for a group of older listeners. We expected individual performance on the Digit-Symbol Substitution Test (DSS, part of the Wechsler Adult Intelligence Test, 2004), as an index of information-processing speed, to relate to the ability to rapidly pick up the regularities in the ways vowels were replaced. Secondly, we expected performance on the Trail Making Test (TMT; Reitan, 1958) as an index of executive functioning or, more specifically, task switching, to relate to learning of the novel accent: Cognitive flexibility may be required to match novel pronunciations of words to stored unaccented representations.

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Method

Participants

Twenty younger adults (5 men, age: 18–41, *M* = 23.3, *SD* = 5) and 30 older adults (11 men, age: 65–87, *M* = 74.1, *SD* = 6) participated in the experiment. All were native monolingual speakers of Dutch, with no history of oral or written language impairment or of neurological or psychiatric disease. All participants gave written informed consent and were paid 10 euros for their participation or received course credit (younger group only). Education level for the older adults was expressed on a scale from 1 (*primary school education*) to 5 (*master's or doctoral level*). Mean education of the older adults was 3.6 (*SD* = 1.3, range 2–5). The younger participants were all undergraduate students at Radboud University Nijmegen. All younger adults stated not having any hearing problems.[1]

Stimuli

The test stimuli set consisted of 120 sentences in Standard Dutch (SD) and the same 120 sentences (cf. Appendix A in supplementary material) in the novel accent, spoken by a female SD speaker. The sentences were taken from the Dutch speech reception threshold (SRT) corpus (Plomp & Mimpen, 1979). To obtain the novel accent sentences, we asked the speaker to read Dutch sentences with an orthography that was altered systematically to elicit vowel pronunciations as listed in Table 1. Average duration per sentence was 2.62 s in the SD condition and 2.82 s in the novel accent condition. Praat (Boersma & Weenink, 2003) was used to save all sentences into separate files with begin and end trimmed at zero crossings and resampled at 22050 Hz to peak-normalize all sentences to 99% of their maximum amplitude and to save them at 70 dB (Sound Pressure Level).

Procedure

Pure-tone audiometry and cognitive measures of the older participants. Hearing acuity was assessed with a portable Maico ST 20 audiometer in a silent booth. Only one participant had hearing aids, which he was asked not to wear during the experiment. Pure-tone average was 25.5 dB (Hearing Level; *SD* = 9.8, median: 25.0, range: 10–43).

Older participants' mean substitution time per symbol in the DSS was 2.1 s/symbol (*SD* = 0.4). This was corrected for the time needed to copy a symbol (*M* = 1.0 s/symbol; *SD* = 0.2); mean corrected coding time (substitution time minus copying time) was 1.1 s/symbol (*SD* = 0.3). This latter score was taken as individual processing speed. Mean time to complete Part A of the TMT (TMT–A) was 48.7 s (*SD* = 14.4) and 95.3 s (*SD* = 27.3) for Part B of the TMT (TMT–B). We took ratio scores of the two subparts (TMT–B/TMT–A), rather than the difference score, as a measure of executive function (Arbuthnott & Frank, 2000) because the difference is greater when participants start slowly (Verhaeghen & De Meersman, 1998).

Adaptive staircase procedure. The SRT (Kalikow, Stevens, & Elliott, 1977; Plomp & Mimpen, 1979) is expressed as the signal-to-noise ratio (SNR) in dB at which listeners can repeat 50% of key words[2] in a sentence presented in speech-shaped noise and is established with a staircase procedure (Baker & Rosen, 2001). The SRT has been used as a clinical measure of speech intelligibility for normal-hearing listeners and (older) listeners with moderate hearing loss (Chien et al., 2008; Dubno, Dirks, & Morgan, 1984; van Wijngaarden, Steeneken, & Houtgast, 2002), and represents a naturalistic measure of listeners' comprehension. The procedure is well suited for dealing with individual differences in baseline performance. It is also

Table 1
Intended Vowel Conversions for Obtaining the Novel Accent

Orthography	Phonetic (IPA)
a → aa	/ɑ/ → /aː/
aa → a	/aː/ → /ɑ/
e → ee	/ɛ/ → /eː/
ee → e	/eː/ → /ɛ/
i → ie	/ɪ/ → /iː/
ie → i	/iː/ → /ɪ/
o → oo	/ɔ/ → /oː/
oo → o	/oː/ → /ɔ/
uu → u	/yː/ → /ʏ/
u → uu	/ʏ/ → /yː/
oe → u	/u/ → /ʏ/
eu → u	/ø/ → /ʏ/
au → oe	/ɔu/ → /u/
ei → ee	/ɛi/ → /eː/
ui → uu	/œy/ → /yː/

Note. The left column shows the altered orthography in the Standard Dutch (SD) sentences, and the right column shows the intended change in pronunciation of the vowel in broad phonetic transcription, using the International Phonetic Alphabet (IPA).

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[1] Background measures of the younger adults (hearing and cognitive test performance) were not available because they were tested at an earlier stage than were the older adults.

[2] The data set used (Plomp & Mimpen, 1979) has a relatively small number of words, so it was unavoidable that some words were repeated across the halves of the experiment. The average number of repeated words across both halves was 36.8 words on average for both groups (a nonsignificant difference between age groups).

not necessary to use precalibration (cf. Peelle & Wingfield, 2005) because individual performance is kept constant at 50% correct by continually changing the noise level depending on the participant's previous response. A further advantage is that the task is easy to understand and does not require extensive training. Here, the adaptive noise task was repeated eight times, resulting in eight blocks of 15 sentences, the first four in the familiar accent to preclude task learning, followed by four blocks in the unfamiliar accent. The SRT was calculated per block.

Participants were instructed to repeat the entire sentence, or as many words as they had heard, in SD. An experimenter immediately scored their responses for the number of correctly repeated key words. Participants received no explicit feedback. All stimulus lists were randomized to ensure that all sentences occurred equally often in both accents. All participants were tested individually in a sound-treated booth. The stimuli were presented over headphones (Sennheiser HD477). The sound level was set once at a comfortable level for the younger group and once for the older group, and this initial setting was not changed within groups. The duration of the experiment was approximately 30 min.

Results

First, the data of both groups were compared to investigate whether older adults' listening performance was differentially affected by accented speech compared with that of younger adults and to evaluate learning across both groups.

We investigated the effects of the following variables on SRT in a repeated-measures analysis of variance (ANOVA), with the between-subjects variable age group (younger vs. older) and the within-subjects variable accent, having two levels (SD and novel accent) and the continuous variable block. A main effect was found for age group, $F(1, 48) = 31.3$, $p < .001$: Older listeners generally needed more favorable SNR for 50% recognition accuracy. A second main effect was found for accent, $F(1, 48) = 973.7$, $p < .001$: Listeners could tolerate less noise for the novel accent. Effects were found for block, $F(3, 46) = 16.8$, $p < .001$ and Block × Accent, $F(3, 46) = 7.2$, $p < .001$, indicating perceptual learning in the novel accent condition. The Age Group × Accent interaction was significant as well, suggesting that the novel accent was more detrimental to speech understanding for the older listeners, $F(1, 48) = 29.8$, $p < .001$. An Age Group × Block interaction, $F(3, 46) = 3.1$, $p < .05$ appeared to have been driven by the result pattern in the novel accent condition: There was no Age Group × Block interaction when we restricted the data to the subset of the SD blocks. More importantly, there was an Age Group × Accent × Block interaction, $F(3, 46) = 3.7$, $p < .05$, which indicates that the pattern of improvement over blocks in the novel accent condition differed across groups. The younger adults showed improvement with longer exposure (see Figure 1), but the curve of the older adults appears *U*-shaped: There was considerable learning from the first to the second block, and then performance seemed to deteriorate again. We also ran a post hoc analysis on the maximum amount of perceptual learning in young and older listeners by subtracting each participant's best SRT (obtained in the third or fourth accent block) from the SRT in the first accent block (mean maximum improvement was 2.78 dB for the older adults and 3.78 dB for the younger adults). A *t* test on these difference scores did not reveal an age group difference in adaptation ($t < 1$).

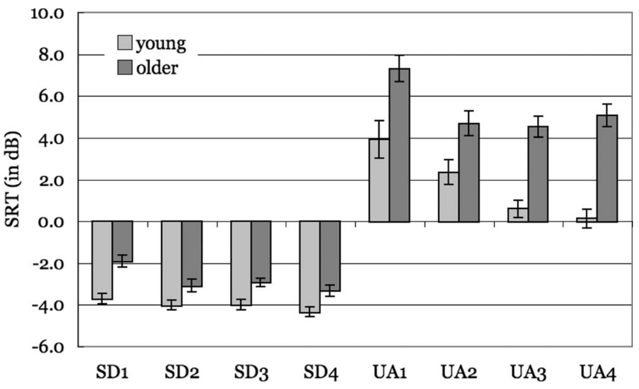

Figure 1. Average speech-reception threshold (SRT) in dB per block of 15 sentences. The left four blocks (SD1–4) represent the first four blocks of Standard Dutch (SD) sentences; the right four blocks (UA1–4) represent the four blocks of the sentences in the unfamiliar accent (UA). Error bars represent one standard error of the mean.

In a second analysis, we analyzed only the older participants' data to investigate which background measures predicted performance and perceptual learning of the novel accent. The background measures were correlated: Age was significantly correlated with hearing loss (Pearson's $r = .42$, $p < .05$), and age was also correlated with processing time (Pearson's $r = .46$, $p < .05$). However, neither of the two cognitive measures was correlated with hearing loss. The two cognitive measures (the DSS measure and the TMT ratio measure) were also not correlated ($r < 0.1$), suggesting they tapped into different cognitive processes.

We implemented mixed-effect models using the lmer function in the lme4 package (Bates & Sarkar, 2005) in the R statistical program. We performed linear regression modeling to determine the predictive value of the background measures on SRTs and their interaction with the design variables accent and block. Mixed models are hierarchical or multilevel models that incorporate both fixed and random effects. Accent was entered as a fixed categorical variable, block was entered as a continuous predictor variable, and participant was entered as a random variable. The background measures (individual hearing acuity, DSS time, the TMT measure of executive function, education level, gender, and age) were entered as covariates. Our main questions were whether any of the background measures would predict the impact of the novel accent on individual SRTs and how much the SRT would improve over novel accent blocks. Systematic stepwise model comparisons using likelihood ratio tests established the best fitting model. *P*-values for the models were calculated based on Markov chain Monte Carlo simulations ($n = 10{,}000$) using the pvals.fnc function from the language R package for the R statistical program (Baayen, 2007). Age, gender, educational level, and the measure of processing speed did not predict performance, nor did they interact with accent or block. The overall best fitting model explaining SRTs contained accent, block, hearing loss and TMT performance. The model had significant effects of accent, $\beta = 6.33$ ($SE = 0.88$), $t = 7.17$, $p < .001$ and of block, $\beta = -0.55$ ($SE = 0.11$), $t = -5.12$, $p < .001$, as was shown in the group comparison analysis. Hearing loss affected SRTs, $\beta = 0.07$ ($SE = 0.03$), $p < .05$, and interacted with accent, $\beta = 0.09$ ($SE = 0.02$), $p < .001$. The more hearing loss one had, the higher the SRTs and the greater the impact of the novel accent on performance. The TMT measure did not affect general performance, but its interaction with accent significantly improved the model, $\beta = 0.92$ ($SE = 0.42$), $p < .05$. Increased difficulty in the executive function task thus predicted increased difficulty in understanding the novel accent.[3]

Mixed-effect models do not output the model's explained variance as multiple linear regression models do. To get an idea of explained variance, we also fed our data in a multiple linear regression model without random effects. The resulting model of the SRTs containing only our design variables accent and block accounted for 74% of the variance. When the Hearing Loss × Accent interaction was added, the model accounted for 79% of the variance. When the Accent × TMT Performance interaction was added as well, the model accounted for 80% of the variance: Adding this last interaction also significantly improved the model fit.

None of the background measures interacted with block (or, more specifically, predicted improvement over blocks in the novel accent condition). Learning for the older participants appeared to be concentrated in the first two novel accent blocks. Running analyses on two data subsets (first two blocks vs. last two blocks) did not show other covariates of learning. The subset analyses did show that the Accent × TMT Performance interaction found in the overall results was mainly carried by the first two blocks, as we did not find the interaction in the subset of the last two blocks.

Discussion

The results show first that the older listeners had considerably more difficulty understanding the novel accent than did the younger listeners. Second, the older listeners showed a different pattern of learning; they started off with considerable improvement in accent from Block 1 to 2 (2.63 dB), an improvement that was larger than that for the young adults (1.57 dB). Therefore, the learning rate was not slower, and the magnitude of adaptation was not significantly decreased for the older participants either. The quick learning supports the idea that the ability to adapt to various new aspects of speech remains stable throughout the life span.

These results of similar rate and magnitude of learning for young and older adults are therefore in line with the work of Peelle and Wingfield (2005), who also found that older adults' performance asymptoted relatively early. This early asymptote could have been due to fatigue. However, fatigue cannot fully account for it, as similar results have been found when fatigue effects were ruled out (Howard et al., 2004). It thus appears that it is not the initial adaptation process that differs between age groups, but the speech manipulation's general impact, combined with the early learning asymptote in the older group.

The results show that none of the background measures predicted the older adults' adaptation pattern. It was expected that rate and magnitude of adaptation would differ for the two age groups, as was found for skill learning in a number of visual modality studies (Head, Raz, Gunning-Dixon, Williamson, & Acker, 2002; Kennedy, Rodrigue, Head, Gunning-Dixon, & Raz, 2009; Rodrigue, Kennedy, & Raz, 2005). As both age groups showed a similar adaptation pattern in our study, the lack of associations between adaptation and background measures may not be surprising.

However, our results show associations between auditory and cognitive background measures and older listeners' performance on the novel accent sentence blocks. Both hearing acuity and the measure of executive function predicted an individual's relative difficulty in understanding the sentences in the novel accent. Hearing impairment evidently interferes with identifying the speech sounds and thus with processing the peculiarities of the novel accent and making novel representations. Contrary to our expectation, processing speed was not related to individual difficulty with the novel accent. This suggests that making sense of the novel accent may not have been demanding with respect to processing speed: Sentence stimuli were read out relatively carefully and slowly, particularly in the novel accent condition (see Stimuli section). Executive function or task switching, as measured in the TMT, predicted the impact that the novel accent had on performance, particularly in the first two accent blocks. This confirmed our prediction that cognitive flexibility is required to match novel deviant pronunciations to stored unaccented word representations.

Executive function is a relatively new associate of novel task performance, as earlier individual difference studies on perceptual learning in the visual domain mainly found correlations between perceptual learning and measures of memory or fluid reasoning (Kennedy et al., 2009). Second, the latter correlations were found within the same modality, as the predictor measures and the to-be-learned skill were tested in the visual domain. Our cognitive measures were obtained through paper-and-pencil tasks. If age-related sensory decline affected performance, it must have been in the visual domain. Our results therefore show that auditory and nonauditory factors predict listening performance.

A recent aging study has shown that decline in executive function (as measured by TMT performance) preceded decline in memory (as measured by immediate and delayed verbal recall) by about 3 years (Carlson, Xue, Zhou, & Fried, 2009). These results make TMT performance an early measure of the cognitive flexibility associated with the task of understanding a novel accent. However, since performance scores on the cognitive measures were not available for the younger adults, we do not know whether individual differences in cognitive flexibility would also relate to difficulty with the novel accent in younger adults. This remains for future study.

Our results add to a growing body of studies addressing how aging affects speech perception (Golomb et al., 2007; Peelle & Wingfield, 2005). Our study further confirms earlier results that older listeners can adapt effectively to new speech types. The type of variation older listeners had to adapt to in the present study—accented speech—is a naturalistic one that they may (frequently) encounter in everyday life. Finally, the results show that declining hearing acuity, as well as poorer executive control, results in poorer language comprehension in challenging listening conditions.

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[3] Both interactions (Accent × Hearing Loss and Accent × TMT Performance) approached significance in a subgroup of young-old listeners (16 listeners < 75) and in a subgroup of old-old listeners (14 listeners > 75 years and older).

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