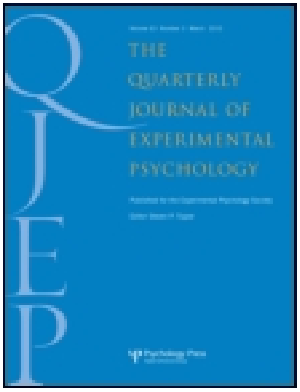

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Predicting foreign-accent adaptation in older adults

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Predicting foreign-accent adaptation in older adults

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We investigated comprehension of and adaptation to speech in an unfamiliar accent in older adults. Participants performed a speeded sentence verification task for accented sentences: one group upon auditory-only presentation, and the other group upon audiovisual presentation. Our questions were whether audiovisual presentation would facilitate adaptation to the novel accent, and which cognitive and linguistic measures would predict adaptation. Participants were therefore tested on a range of background tests: hearing acuity, auditory verbal short-term memory, working memory, attention-switching control, selective attention, and vocabulary knowledge. Both auditory-only and audiovisual groups showed improved accuracy and decreasing response times over the course of the experiment, effectively showing accent adaptation. Even though the total amount of improvement was similar for the auditory-only and audiovisual groups, initial rate of adaptation was faster in the audiovisual group. Hearing sensitivity and short-term and working memory measures were associated with efficient processing of the novel accent. Analysis of the relationship between accent comprehension and the background tests revealed furthermore that selective attention and vocabulary size predicted the amount of adaptation over the course of the experiment. These results suggest that vocabulary knowledge and attentional abilities facilitate the attention-shifting strategies proposed to be required for perceptual learning.

Keywords: Speech perception; Perceptual adaptation; Audiovisual information; Ageing; Individual differences.

Much of everyday speech comprehension occurs under listening conditions that are less than ideal, due to background noise, regional accents, or speech rate differences, to name a few common everyday variations in the speech signal. Listeners are generally able to successfully comprehend speech under such adverse listening conditions. Nevertheless, comprehension is often more effortful and less efficient than under less adverse conditions. For instance, when listeners are performing a semantic verification task (i.e., reporting whether a sentence such as "dogs have four ears" is true or false) spoken in a regional accent they are not familiar with, they show slower response times and higher error scores than when they listen to a known accent or the standard variant of their language (Adank, Evans, Stuart-Smith, & Scott, 2009).

This ability to effectively comprehend speech under challenging listening conditions deteriorates

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as humans age (Dubno, Dirks, & Morgan, 1984), mainly due to a high-frequency hearing loss (Gates, Cooper, Kannel, & Miller, 1990). Independent of elevated hearing thresholds, there are indications that auditory processing—temporal processing in particular—may be impaired in older adults (e.g., Fitzgibbons & Gordon-Salant, 1998; Grose, Hall, & Buss, 2006; Humes, Kewley-Port, Fogerty, & Kinney, 2010, and cf. Gordon-Salant, Frisina, Popper, & Fay, 2010, for an overview of auditory ageing). Additionally, age-related declines in cognitive function (e.g., working memory, mental flexibility; Salthouse, Atkinson, & Berish, 2003) may compromise ease of speech comprehension (cf. Wingfield & Stine-Morrow, 2000). A recent study illustrated this deterioration in the ability to process distorted speech by showing that older adults were more negatively affected by an unfamiliar accent than younger listeners, relative to their performance on standard Dutch (Adank & Janse, 2010). This is problematic because in societies that become increasingly multicultural, such as the UK, older adults may have to interact more often with people coming from different language backgrounds, including health care providers.

Nevertheless, even though such challenging listening conditions can pose problems for listeners, there is compelling evidence that listeners are able to quickly perceptually adapt to distortions of the speech signal, including noise-vocoded speech (Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995), time-compressed speech (Dupoux & Green, 1997), synthetic speech (Greenspan, Nusbaum, & Pisoni, 1988), and foreign (Bradlow & Bent, 2008; Clarke & Garrett, 2004) and regional (Clopper & Bradlow, 2008; Maye, Aslin, & Tanenhaus, 2008) accented speech. This ability to quickly adapt appears to be preserved in older adults (Golomb, Peelle, & Wingfield, 2007; Peelle & Wingfield, 2005), although it should be noted that there are differences between age groups. For instance, older adults were found to adapt to time-compressed speech at a rate and magnitude comparable to younger adults, when equated for starting accuracy with younger adults (Peelle & Wingfield, 2005). However, unlike younger adults, older adults failed to transfer this learning to a different compression rate and did not show additional benefit with additional practice with time-compressed sentences. In another study, Adank and Janse (2010) compared younger and older adults on their ability to perceptually adapt to speech in an unfamiliar accent, presented in background noise. They equated task difficulty across listeners through the use of an adaptive staircase procedure in which task performance was kept constant at 50% (Kalikow, Stevens, & Elliott, 1977; Plomp & Mimpen, 1979). Adaptation to the accented speech was assessed by evaluating the change in signal-to-noise ratio at which the sentences were presented to the listeners. A decrease in signal-to-noise ratio over the course of the experiment (which means that participants could gradually tolerate more noise) signalled adaptation. The results showed that the age groups ended up with a similar amount of adaptation to the speech in the unfamiliar accent, but that the age groups differed in their adaptation curve: Older adults reached plateau performance earlier whereas the younger listeners continued to improve with added exposure.

The ability to adapt in older adults may be affected by age-related declines in cognitive abilities (cf. Kennedy, Rodrigue, Head, Gunning-Dixon, & Raz, 2009). In this study, we therefore focused on individual differences in the ability to adapt to distorted speech. We investigated which individual abilities predict adaptation in order to study the mechanisms underlying perceptual learning. Older adults may show more variability in speech performance, and in their auditory, linguistic, and cognitive abilities, than younger adults. Service and Craik (1993) found that a repetition task (as an index of phonological memory) predicted foreign vocabulary learning in their sample of older adults, but the correlation was nonsignificant in their sample of younger adults. We therefore tested adaptation to a novel accent in a group of older adults only, in order to gain more insight into individual perceptual plasticity for effective communication.

In recent years, there has been a growing understanding of the role of cognitive factors in the decline of the ability to comprehend speech in challenging listening situation situations (Akeroyd, 2008; Pichora-Fuller, & Singh, 2006). Akeroyd's literature survey (2008) shows that measures of working memory (reading span in particular) were most often found to relate to speech comprehension ability in challenging conditions. Adank and Janse (2010) investigated the mechanisms underlying the learning process by relating older listeners' adaptation to and comprehension of accented speech to their hearing acuity and to measures of cognitive function. They found that individual hearing acuity and a measure of executive function (the Trail-Making Test, Reitan, 1958, which tests attention-switching control) predicted how well older adults could understand sentences in an unfamiliar accent. Nevertheless, they did not find a reliable predictor for perceptual adaptation to the accented speech. They tested the relationship between perceptual learning (i.e., an increase in the amount of noise participants could tolerate in order to arrive at a fixed identification accuracy level) and hearing acuity (average pure-tone threshold in the better ear), mental flexibility (as measured in the Trail Making Test), and processing speed (as indexed by performance in the Digit-Symbol Substitution Test, which is part of the Wechsler Adult Intelligence Test (2004).

In the present study, we first aimed to determine whether we could identify predictors accounting for individual differences in accent adaptation ability, using a task that allowed for more fine-grained temporal analysis of the adaptation process and that allowed participants to listen to the speech signal in quiet conditions. Note that Adank and Janse (2010) used a task in which improvement was assessed every 15 sentences, and stimuli were presented in background noise. Also, we now specifically included memory measures to investigate their relation with adaptation: Both auditory verbal short-term memory and working memory measures were included. Being able to keep the accented sentence in memory may be helpful to learn in what (systematic) ways the accented speech deviates from the standard pronunciation and to use these regularities in processing subsequent sentences. There are numerous indications that memory measures relate to word learning in either first or second language acquisition (Atkins & Baddeley, 1998; Baddeley, Gathercole, & Papagno, 1998; Gathercole, Hitch, Service, & Martin, 1997; Gupta & MacWhinney, 1997; Papagno, Valentine, & Baddeley, 1991; Papagno & Vallar, 1992; Service, 1992; Service & Kohonen, 1995). Gupta (2003) found relations between memory and word learning and argued that sequence memory is directly involved in temporarily maintaining the serial order of the sequence of sublexical units constituting the novel word form and in connecting the phonological and semantic representations (and cf. Vaughan, Storzbach, & Furukawa, 2006). Further, there is more recent evidence from the visual processing literature that working memory predicts learning (Kennedy et al., 2009). Kennedy et al. used a fragmented pictures identification task where observers view line drawings of common objects in descending order of fragmentation. With more practice, observers are able to identify objects more quickly or at a greater level of fragmentation. Working memory measures (both verbal and nonverbal) were found to predict learning in this fragmented pictures identification task, via their effect on a fluid intelligence measure. Efficient working memory may facilitate discarding false hypotheses that preclude correct identification of degraded stimuli (cf. e.g., Engle, Kane, & Tuholski, 1999; Kane, Conway, Hambrick, & Engle, 2007, on the relation between working memory and inhibitory control). In listening to a foreign accent, listeners also have to learn to reject "false friends": word forms that immediately map onto a standard-Dutch word, but actually mean something else.

We also investigated whether hearing loss and a linguistic measure (vocabulary knowledge) were predictive of adaptation to the novel accent. Poorer hearing (due either to hearing loss or to poorer auditory processing) may compromise perceptual learning, as a poorer input signal provides a more fragmented picture of the novel accent, which should make it more difficult to adapt to. Note, however, that Gordon-Salant, Yeni-Komshian, and Fitzgibbons (2010) found no effect of hearing thresholds on adaptation to Spanish-accented speech. Linguistic ability may very well be a general predictor of speech processing performance, but may also relate to perceptual adaptation in our study, given the linguistic nature of our distortion. A number of studies have shown that language-related variables, such as vocabulary and grammatical knowledge, are robust predictors of proficiency in a second language (Sparks, Patton, Ganschow, & Humbach, 2009; Van Gelderen et al., 2003). Thus, linguistic ability, or individual language aptitude (Carroll & Sapon, 1959/2000), operationalized in our study as vocabulary knowledge, was expected to be predictive of novel accent adaptation.

Second, we evaluated the influence of presentation modality of the speech material on adaptation, to address the issue of ecologically valid communication settings. Typically, both auditory and visual information is available when conversing with others in everyday settings. Successful comprehension of speech in everyday settings requires the integration of both auditory and visual information. The auditory signal may be less available as humans age, due to age-related hearing loss that particularly affects sensitivity to high-frequency sounds. This could partly be compensated for by the availability of visual information in audiovisual presentation (Grant & Walden, 1996; MacLeod & Summerfield, 1987; Walden, Prosek, Montgomery, Scherr, & Jones, 1977), though one should note that ageing also negatively affects visual processing and thus lip-reading ability (Cienkowski & Carney, 2002; Sommers, Tye-Murray, & Spehar, 2005; Tye-Murray, Sommers, & Spehar, 2007).

However, it is unclear whether older adults can make use of available visual information about the speaker when *adapting* to the speaker's accent. A recent study of younger listeners found that adaptation to noise-vocoded words was improved when visual information was present compared with when only auditory information was present (Kawase et al., 2009). Note that visual information may be particularly beneficial in the case of *acoustically* degraded speech, because it provides information that is complementary to the degraded acoustics: Information about place of articulation of consonants may be particularly salient in visual speech (such as lip opening; Sumby & Pollack, 1954). This would be less important in the case of listening to acoustically intact speech in quiet conditions. Nevertheless, audiovisual information may still help in understanding the speech because the visible speech provides information about speech segments that is redundant as well as complementary to the auditory signal (Jesse & Massaro, 2010) and thus facilitates perception. Furthermore, audiovisual, rather than auditory-only, presentation of the speech may help at a more general level: The time-locked co-modulation of speech movements (including movements signalling prominence, such as head nodding and movement of eyebrows) may help the listener to keep attending the speaker and thus to adapt to the speaker's unfamiliar way of talking.

In the present study, we presented two groups of older listeners with accented sentences in auditory-only (A) and auditory–visual (AV) modalities. We tested accent processing speed and monitored adaptation in both groups using a speeded semantic verification test (i.e., judging whether a statement such as "rats have teeth" is true or false). We related each individual's general performance, as well as individual perceptual adaptation, to their auditory, cognitive and linguistic abilities.

If the available visual information improves processing and adaptation, then the AV group should show faster and more effective processing than the A group and should also show a faster rate of adaptation. Furthermore, we investigated whether the audiovisual modality was more beneficial for some participants than others: The addition of visual information might be more beneficial for those with poorer hearing and/or for those with poorer selective-attention abilities.

Method

Participants

Two groups of older adults ($N = 66$) volunteered to participate in the experiment. They had responded to an information letter with a call for participants. They received this information letter either because they had participated in a language experiment at the Max Planck Institute for Psycholinguistics before, or because they had signed up for participation after reading a short advertisement in a local newspaper (for the Nijmegen area). The adults were randomly allocated either to the auditory-only group (*N* = 33, of which 14 were male, average age = 74 years, *SD* = 6.0 years, range = 65–89 years), or to the auditory–visual group (*N* = 33, of which 11 were male, average age = 73 years, *SD* = 4.6 years, range = 64–82 years). All were native monolingual speakers of Dutch, with no history of oral or written language impairment or of a neurological or psychiatric disease (as self-reported on a questionnaire). All participants gave written informed consent and were paid for their participation (€8 per hour).

All participants were asked to bring their glasses to the lab, if they had any. In the experimental booth, they could then decide which glasses to wear for watching the computer screen, and for doing any paper-and-pencil task or for filling out the questionnaire. No further test was administered of their vision or visual processing speed.

Stimulus material

The stimulus set consisted of 98 sentences recorded in standard Dutch and in an unfamiliar (novel) accent. These 98 sentences were selected from a larger set of 100 sentence pairs (thus from 200 sentences). Sentence pairs were two related sentences: one being a true statement (e.g., *Bevers bouwen dammen in de rivier;* English: “Beavers build dams in the river”), and the other false (e.g., *Bevers groeien in een moestuin;* English: “Beavers grow in a vegetable patch”). Half of the 98 sentences were true statements, and the other half were false.

Importantly, 18 sentences were selected for presentation in standard Dutch only (half of them true, half of them false): These were used as practice trials to familiarize participants with the task of sentence verification. The other 80 sentences were presented in the novel accent in the test phase. In other words, there was no overlap in sentence content between the standard-Dutch sentences presented during the practice part and the accented sentences presented in the test phase. Within the 18 sentences selected as standard-Dutch practice trials, the number of true–false sentence pairs was limited to avoid too much repetition of content words. The same held for the 80 sentences selected for presentation in the novel accent.

The novel accent, as used previously (Adank, Hagoort, & Bekkering, 2010; Adank & Janse, 2010), was created by instructing the speaker to read sentences with an adapted orthography. The orthography was systematically altered to achieve the following changes in all 15 Dutch vowels as listed in Table 1. All sentences are listed in the Appendix. Only vowels bearing primary or secondary stress were included in the orthography conversion. An example of a sentence in standard Dutch and a converted version are given below, including a broad phonetic transcription using the International Phonetic Alphabet (International Phonetic Association, IPA, 1999):

“Ratten hebben tanden” (Standard Dutch) /rɑtə hɛbə tɑndə/

After conversion: “Raten heben taanden”

/raːtə heːbə taːndə/

Our reasons for using a novel accent were twofold: first, to avoid a confound between speaker and accent, thus making sure that the listeners

Table 1. *Vowel conversions for obtaining the novel accent*

Orthography	*Phonetic (IPA)*
a → aa	/ɑ/ → /a:/
aa → a	/a:/ → /ɑ/
e → ee	/ɛ/ → /e:/
ee → e	/e:/ → /ɛ/
i → ie	/i/ → /I/
ie → i	/i/ → /I/
o → oo	/ɔ/ → /o:/
oo → o	/o:/ → /ɔ/
uu → u	/y:/ → /y/
u → uu	/y/ → /y:/
oe → u	/ɛ/ → /e:/
eu → u	/ø/ → /y/
au → oe	/ɔu/ → /u/
ei → e	/ɛí/ → /e:/
ui → uu	/œy/ → /y/

Note: The left column shows the alteration of the orthography from standard Dutch, and the right column shows the intended change in pronunciation of the vowel in broad phonetic transcription, using the International Phonetic Alphabet (IPA; International Phonetic Association, 1999).

adapted to the accent and not (also) to the speaker's voice. Second, we wanted to be sure listeners were all equally unfamiliar with the accented speech (Adank et al., 2009; Floccia, Goslin, Girard, & Konopczynski, 2006).

Note that the perception of vowels is not as affected by (age-related) high-frequency hearing loss as consonant perception would be (but cf. Vongpaisal & Pichora-Fuller, 2007, on age-related decline in periodicity coding affecting vowel perception). Therefore, the way in which the novel accent deviates from standard Dutch is relatively salient to the older participant sample of the present study.

Full-colour-motion video recordings were made in a quiet room of a 37-year-old female native speaker of Dutch. Recordings were made of two versions of the sentences in the Appendix: a standard-Dutch version and a novel-accent version. The speaker sat in front of a dark blue background whilst reciting the sentences and was filmed from her upper torso up: The speaker faced the camera so that the front of her face was clearly visible.

The speaker was instructed to keep a neutral facial expression with respect to the truth value of the sentences. Four repetitions of each stimulus were recorded, and the authors (both trained phoneticians) made sure to select the version that sounded most novel-accent consistent and to not select a version with a facial expression or head movement (such as nodding) that might be biasing towards either truth value. All 80 selected accented sentences were inspected for accent consistency (i.e., did the speaker pronounce the sentences in the Appendix as instructed?). There were only 3 sentences containing one inconsistent vowel (i.e., vowels being pronounced as in the standard-Dutch word). The speaker was thus highly consistent in her production of the accent (if we take each sentence to contain minimally three stressed vowels, 99%, i.e., 237 out of 240, of the vowels were accent consistent). Also, collapsed over the 80 selected novel-accent sentences, the speaker's mean speech rate in the novel-accent condition was 4.5 syllables per second ($SD = 0.8$).

The video recordings were made with a Canon HV30 camera, and audio recordings were made using a Sony ECM-MS907 microphone attached to the video camera. The recordings were edited using Adobe Premiere CS4. The recordings were saved as individual files.

Auditory, cognitive, and linguistic background tests

Hearing thresholds. Hearing thresholds were assessed with a portable Maico ST 25 screening audiometer in a sound-attenuating booth. Only air-conduction thresholds were established.[1] Five participants had hearing aids in one or two ears, which they were asked not to wear during the experiment (nor during the audiometry test obviously). Given the high-frequency hearing loss associated with ageing, a pure-tone average threshold was computed over 1, 2, and 4 kHz (instead of over 0.5, 1, and 2 kHz) for each participant's better ear. This pure-tone average threshold (PTA) was 27.2 dB HL ($SD = 11.8$): The higher the participants' PTA, the poorer their hearing acuity. Pure-tone average threshold in the better ear did not differ significantly between the auditory-only and audiovisual participant groups, $t(64) = 1.2$, $p > .1$.

Cognitive measures

Attention-switching control. Participants were tested on the Trail-Making Test (TMT; Reitan, 1958), a paper-and-pencil task, as a measure of executive function, or more particularly, attention-switching control. Attention-switching control, as a form of cognitive flexibility, was related to general performance on the accented materials in our previous study (Adank & Janse, 2010). Mean time to complete Part A of the TMT, in which participants have to connect 25 digits (in ascending order), was 54.6 s ($SD = 16.7$). Mean time to complete Part B, in which participants have to connect letters and digits (alternating between the two dimensions: 1–A–2–B–3–C, etc.), was 104.0 s ($SD =$

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[1] Note that there may be suprathreshold aspects of hearing (such as temporal processing, cf. Gordon-Salant, Frisina, Popper, & Fay, 2010) that impact on speech processing ability. Those were not measured in this study.

35.5). We took ratio scores of the two subparts (TMT–B/TMT–A), rather than the difference score, as a measure of attention-switching control (Arbuthnott & Frank, 2000) to take general slowing into account (Verhaeghen & De Meersman, 1998). Mean ratio was 1.95 ($SD = 0.48$): The higher the ratio, the poorer a participant's attention-switching control. Mean score on this attention-switching control measure did not differ between the auditory-only and audiovisual participant groups, $t(64) = 1.0$, $p > .1$.

Selective attention. In this computerized variant of the classic flanker task (Eriksen & Eriksen, 1974), participants responded to visual stimuli by clicking either the "z" or the "/" key on the keyboard. A row of five white symbols is shown (in Arial 80 font size), against a black background. The middle symbol in the row (the target) is a leftward- or rightward-pointing arrowhead. The target is flanked on either side by two congruent or incongruent arrows (same or opposite direction), or by neutral lines (e.g., for a > target: > > > > > as the congruent condition; < < > < < as the incongruent condition; and - - > - - as the neutral condition). The task of the participant was to indicate the direction of the central (middle) target symbol by pressing the "z" key for leftward pointing and the "/" key for rightward pointing, and to maximize speed and accuracy. Each trial started with a beep (a 400-Hz pure tone, presented at 50 dB SPL) and a fixation cross that remained on the screen for 250 ms. Following this fixation cross, the symbol string was presented for 1,500 ms. After these 1,500 ms, the string was removed, and participants could no longer respond. Intertrial time was 1,000 ms. There were six different stimuli (two pointing directions for the target, times three different flanker conditions). These six different stimuli were each presented 12 times in the test part (order of trial presentation was randomized for each participant) to make 72 trials. Before the test part started, 6 practice trials were presented (i.e., the six different stimuli).

Mean accuracy of the responses (pooled over participants) was 93% correct ($SD = 12$). Accuracy was lowest and most variable in the incongruent condition (86%, $SD = 23.3$), while accuracy in the congruent and neutral conditions was 97% ($SD = 8.2$).

Mean response times (collapsed only over correct responses) in the three conditions were 612 ms (from visual presentation onset) in the congruent condition ($SD = 195$), 758 ms in the incongruent condition ($SD = 283$), and 600 ms ($SD = 192$) in the neutral condition. A repeated measures analysis of variance (ANOVA) of each participant's mean response time (RT) in all three conditions showed a significant effect of condition on RTs, $F(2,\ 64) = 51.1$, $p < .001$. Pairwise comparisons (Bonferroni-corrected for multiple comparisons) showed that the incongruent condition was significantly slower than the neutral and congruent conditions ($p < .001$) and that the difference between the neutral and congruent condition was marginally significant ($p = .064$). Individual performance on this task was determined by computing the flanker interference effect: Each participant's mean logRT in the neutral condition was subtracted from each participant's mean logRT in the incongruent condition and was then divided by the mean logRT in the neutral condition. Mean flanker effect was 0.04 ($SD = 0.02$): The higher a participant's flanker effect, the poorer their selective attention. Mean score on this measure did not differ between the auditory-only and audiovisual participant groups ($t < 1$, *ns*).

Auditory short-term memory. An auditory nonword repetition task was used as an index of verbal/phonological short-term memory (Botting & Conti-Ramsden, 2001; Gathercole & Baddeley, 1996; Thorn & Gathercole, 1999). Others have referred to this task as indexing phonological storage (e.g., Gathercole, 2006), phonological buffer capacity (Bates et al., 2011), or phonological working memory (Gathercole, Willis, Baddeley, & Emslie, 1994; McGettigan et al., 2011). The task has been widely used in research on developmental dyslexia (e.g., Ramus & Szenkovits, 2008) and specific language impairment (Botting & Conti-Ramsden, 2001).

The task consisted of the presentation of 50 nonwords, all of which were phonotactically legal in Dutch (de Jong & van der Leij, 1999). The speaker was a professional speech therapist and female native speaker of Dutch who spoke at a consistently slow and clear speaking rate. The nonword items were presented over headphones at a fixed mean intensity level of 80 dB SPL. Participants were seated in a sound-attenuating booth. Each nonword was presented only once, after which participants were asked to repeat the nonword. Intertrial time was three seconds. Nonwords of different syllable lengths (two to five syllables long) were presented intermixed, but the order in which they were presented was kept constant for all participants. Responses were recorded to allow for offline scoring. Transcription and scoring was done by a native speaker of Dutch. If all syllables of a particular item were reproduced correctly, a score of 1 was obtained. If not all syllables were repeated correctly, a proportion correct was computed (number of correctly repeated syllables divided by total syllable number for that target nonword). Maximum score for the entire task was thus in principle 50 (for 50 correctly repeated nonword items). Mean score for this task was 31.0 ($SD = 6.7$). Higher scores reflected better auditory verbal short-term memory.[2] Mean scores on this task of the auditory-only and audiovisual participant groups did not differ, $t(64) < 1$, *ns.*

Working memory. A digit span task (with backward recall, a subpart of the Wechsler Adult Intelligence Test, 2004) was used to measure individual working memory capacity. In the computerized variant of this task used here, a series of digits would flash up in the centre of the computer screen. Each digit was presented during one second and with one second in between consecutive digits. Digits were presented in a large white font (Arial, font size 100) against a black background. After presentation of the digit sequence (e.g., 3 6 2), the participant was prompted to recall the digits in the reverse order (e.g., 2 6 3). The participant was first presented with two 3-digit trials to become familiarized with the task. They would then be tested on 2- up to 8-digit sequences (two trials for each sequence length, making up 14 trials in total). Individual performance on this task was determined by computing the proportion of correctly recalled digit sequences (out of 14 test trials): The higher the proportion, the better working memory. Mean proportion correct in this task was .36 ($SD = .13$): The higher the score, the better working memory this participant has. Mean working memory score did not differ between the auditory-only and audiovisual participant groups, $t(64) = 1.4$, $p > .1$.

Linguistic measure

Vocabulary test. The vocabulary test was a receptive multiple choice test. Participants were asked to fill in a document in a text-editing program on the computer (Courier font size 15 was used). The test was based on a selection of items from Hazenberg and Hulstijn (1996), a test originally developed for speakers of Dutch as a second language. Target words were presented in a neutral carrier sentence (different carrier sentences for each target)—for example, for the target word *mentaliteit* ("mentality"), the carrier phrase would be: *Wat een vreemde mentaliteit!* ("What a strange mentality!"). Participants had five alternatives to choose from, the last one always being: "I really don't know". New items were added to make the test suitable for native speakers. They were constructed according to the same principles as those employed by Hazenberg and Hulstijn: Words should not be too domain-specific, and it should be possible to use the word in a simple carrier sentence. Care was taken not to introduce any systematicity in the length of the alternatives and the way meanings were described. The test consisted of 60 items. Individual score was defined as

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[2] Since suprathreshold auditory processing abilities (such as temporal and frequency resolution) were not assessed in the current study, we do not know to what extent such auditory processing abilities might be confounded with our auditory short-term memory measure. The strength of the correlation between auditory short-term memory performance and average hearing threshold is addressed below.

Table 2. *Intercorrelations between predictors*

	Age	*Hearing loss*	*Switching*	*Selective attention*	*Auditory STM*	*WM*
Age						
Hearing loss	.41***					
Attention switching (Switching)	.11	−.01				
Selective attention	−.03	.10	.35**			
Auditory STM	−.32**	−.65***	−.15	−.16		
Working memory	−.11	−.30*	−.18	.11	.30*	
Vocabulary knowledge	.11	−.03	−.32**	−.03	.27*	.35**

Note: Pearson correlation coefficients. STM = short-term memory. WM = working memory.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

proportion of correct items (out of 60). Mean score was .87 ($SD = .09$): The higher the score, the better a participant's vocabulary knowledge. Mean vocabulary scores of the two participant groups (auditory-only and audiovisual group) did not differ, t (64) < 1, *ns*.

Intercorrelations between predictors

Table 2 lists all intercorrelations between predictors. The highest correlation was found between hearing loss and auditory short-term memory: Those with more hearing loss had poorer nonword repetition ($r = -.65$, $p < .001$). The two attention measures were correlated as well: Participants with poorer selective attention also generally had poorer attention-switching control ($r = .35$, $p < .01$). Further, as expected, the two memory measures were correlated: Participants with better auditory short-term memory had better working memory skills ($r = .30$, $p < .05$). Vocabulary knowledge was related to three of our four cognitive measures.

Experimental procedure

The pool of older adults participated in two studies (the other one not reported here) and in the battery of background tests described above. To minimize fatigue, we spread testing over two sessions, each of which consisted of a speech perception study and a number of background tests. The sessions were approximately one month apart. The study reported here was done in the first session, as well as the pure-tone audiometry, the selective-attention task, and the auditory verbal short-term memory task (in this order).

All listeners were tested individually in a sound-attenuating booth and received written and oral instructions. Responses were made using a button box. Participants were instructed to use their dominant hand (index finger) for "true" responses (the green-labelled button) and their other index finger for "false" responses (red-labelled button). The stimuli were presented binaurally, over Sennheiser HD 280-13 headphones, at a fixed output level of 80 dB SPL for all participants. Stimulus presentation and response recording were performed using Presentation software (Neurobehavioral Systems, Albany, CA). Response times were measured from the onset of the video. Participants in the AV group were presented with the video and the audio signal, and the participants in the A group only heard the audio signal, while the computer monitor showed a black screen. Participants in the AV group were instructed to watch the screen while listening to the sentences.

Each trial proceeded as follows. First, the stimulus sentence was presented. Second, the program waited for three seconds before playing the next stimulus, allowing the participant to respond. If the participant did not respond within three seconds, the trial was recorded as *no response*. Participants were asked to respond as quickly and accurately as possible and they were told that they did not have to wait until the sentence was finished, allowing for negative RTs, as RT was calculated from the offset of the sound file.

Eighteen familiarization trials in standard Dutch were presented prior to the start of the experiment. The familiarization sentences had been produced by the same speaker. The 80 novel-accent test sentences (with different sentence content from the 18 standard-Dutch practice sentences) were presented in a randomized order per participant, and an equal number of true and false sentences was presented. These standard-Dutch sentences were included to familiarize participants with the speaker and the task of speeded sentence verification. Performance on these practice trials was also analysed as baseline performance. The number of practice (and reference) trials was kept low to minimize the risk of fatigue during the novel-accent test trials. Duration of the accent experiment (practice and test) was 15 min.

Results

General results

Overall accuracy was 72% in the auditory group ($SD = 16$) and 79% in the audiovisual group ($SD = 11$). The 80 novel-accent sentences were divided into eight blocks of 10 sentences in order to establish accent adaptation with more exposure. Figure 1 shows how accuracy improved over the course of the experiment (i.e., over blocks) in both modality groups.

Response times were analysed for correct responses only. Within each data set (the standard-Dutch practice set and the novel-accent data set), valid RTs were restricted to those within three standard deviations from the mean RT (of all correct responses). Figure 2 shows how response times speeded up over the course of the experiment in both modality groups (each block representing 10 trials).

We investigated how many practice trials were required (in both modality groups) to familiarize participants with the speaker's voice and with the task of speeded sentence verification. The results indicated that accuracy performance reached plateau after about 5 practice trials in both presentation modalities: Trial number did not significantly affect performance if only responses to trial numbers 6 and above were analysed (similarly, response speed did not decrease beyond 8 practice trials). We decided to consider the first 5 practice trials as true practice items; we discarded those, and analysed performance on the remaining 13 standard-Dutch practice trials as a performance baseline. Accuracy (with these initial 5 trials discarded) was 91% in the auditory-only group ($SD = 9$) and 95% in the audiovisual group ($SD = 8$). Mean response time (with these initial 5 trials discarded) was 349 ms in the auditory-only group ($SD = 647$) and 281 ms in the audiovisual group ($SD = 547$).

The data were analysed with linear mixed-effects models in R (Version 2.6.2; R Development Core Team, 2008), with the lmer function from the lme4 package of Bates & Sarkar (2005). In this way, both participants and items could be assessed as crossed random factors. For the accuracy models, a binomial logit linking function was included into the models (Jaeger, 2008) between responses (being incorrect, 0, or correct, 1) and predictor variables. The best fitting model for each data set was established through systematic stepwise model comparisons using likelihood ratio tests.

For the two intercorrelations between individual background measures that had correlation coefficients higher than $r = .4$ (cf. Table 2), residual variance was entered, after partialling out the contribution of hearing loss. Thus, given the relatively high correlation between age and hearing loss, the residuals of age were entered, after hearing loss had been partialled out. Likewise, the residuals of auditory short-term memory, after partialling out the contribution of hearing loss, were calculated and entered as a predictor.

Accuracy analysis

Statistical models evaluated the design variables modality group (auditory-only, audiovisual), and whether the correct response should be "true" or "false", and as numerical predictors block (running from 1 to 8, each block consisting of 10 trials) and standardized duration of each sentence. Interactions between these variables were also tested, to test the hypothesis that participants in the AV group would improve more rapidly over trials than participants in the A-only group. After having established the best fitting model without

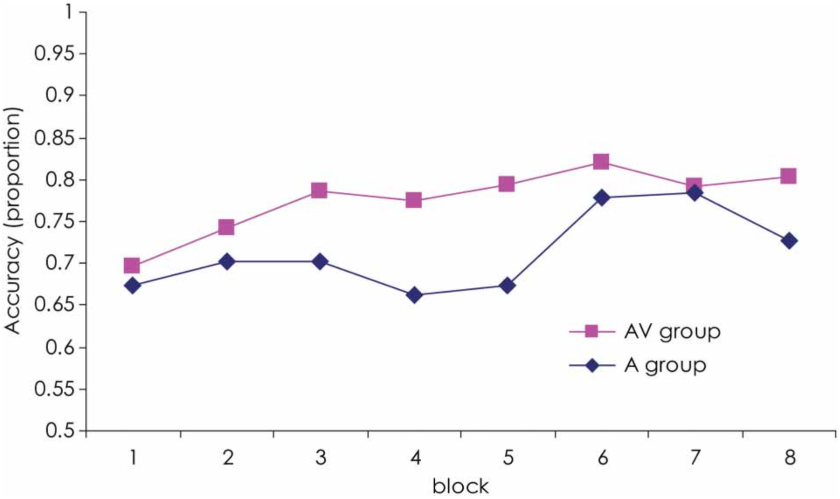

Figure 1. *Mean sentence-verification accuracy in both modality conditions over trial blocks (each block is 10 sentences). AV = audiovisual. A = auditory-only. To view a colour version of this figure, please see the online issue of the Journal.*

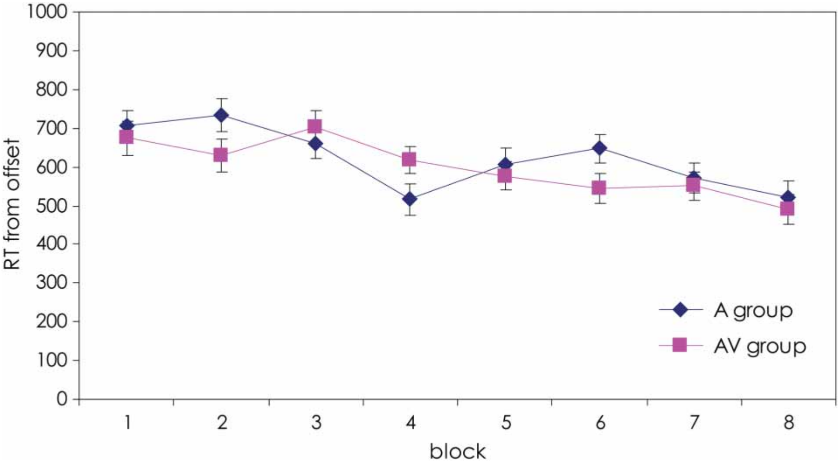

Figure 2. *Mean response time (RT, measured from sentence offset) in both modality conditions over trial blocks. Error bars represent standard errors. AV = audiovisual. A = auditory-only. To view a colour version of this figure, please see the online issue of the Journal.*

individual predictors, individual performance on each of the background tests described above, and each individual's age, were entered as covariates in the accuracy analysis. We then also tested whether the individual covariates interacted with modality and with trial number.

Standard-Dutch practice trials. As laid out above, we analysed a subset of the standard-Dutch trials ($N = 13$) as a performance baseline (but note the low power of this analysis due to the limited number of trials per subject).

The best fitting model (without individual background measures) only included a simple effect of modality. Generally, performance was marginally better in the audiovisual presentation group, $\beta = 0.66$ ($SE = 0.36$), $p = .07$, than in the auditory-only group (mapped on the intercept). After we had entered the individual background measures, the resulting best fitting model included modality and hearing acuity, and an interaction between modality and vocabulary knowledge. As before, accuracy was generally higher in the audiovisual group than in the auditory-only group, $\beta = 0.75$ ($SE = 0.35$), $p < .05$. Participants with more hearing loss showed marginally poorer performance, $\beta = -0.02$ ($SE = 0.01$), $p = .07$. Participants with better vocabulary knowledge showed marginally poorer performance in the auditory-only group—mapped on the intercept: $\beta = -4.85$ ($SE = 2.82$), $p = .09$—but this was modified by modality: Those with better vocabulary knowledge particularly benefited from the audiovisual presentation modality, $\beta = 10.86$ ($SE = 3.95$), $p < .01$.

Novel-accent test trials. The best fitting model without individual background measures showed that performance was marginally better in the AV group, $\beta = 0.43$ ($SE = 0.23$), $p = .06$, than in the A group mapped on the intercept. Sentences that should elicit a "true" response were more accurately responded to than sentences that should elicit a "false" response—the latter being mapped on the intercept: $\beta = 0.48$ ($SE = 0.24$), $p = .05$. Duration of the sentence did not influence verification accuracy. Generally, performance improved over trial blocks, $\beta = 0.09$ ($SE = 0.02$), $p < .001$, but this was not modified by modality group. However, Figure 1 shows that the total magnitude of adaptation is indeed similar for the modality groups (both groups reaching plateau performance at around Block 6), but initial improvement in the first half of the experiment seemed to take off more rapidly in the AV group than in the A group. This was tested on the subset of the first 40 trials. We compared a model that had modality and block as simple effects (as in the best fitting model for the entire dataset) to a model that had an interaction between modality and block. The latter model had a significantly better fit. In this best fitting model for this subset of trials, modality and block interacted, $\beta = 0.26$ ($SE = 0.09$), $p < .01$, showing that there was more improvement over trials in the AV group than in the A group.

The best fitting model for the full test set was taken as a starting point for the individual differences model. All background measures were added, and it was tested whether they interacted with modality and with block. The best fitting model included significant effects of modality, correct response (true or false), and block, and of the covariates hearing acuity, working memory, and auditory short-term memory, and significant interactions between block and vocabulary knowledge and between block and selective-attention ability. None of the individual characteristics interacted with modality, but performance was generally better in the AV group than in the A group, $\beta = 0.67$ ($SE = 0.17$), $p < .001$. Performance was now only marginally better on the "true" statements than on the "false" statements, $\beta = 0.47$ ($SE = 0.25$), $p = .06$. Participants with poorer hearing acuity (higher hearing thresholds) generally showed poorer accuracy, $\beta = -0.04$ ($SE = 0.01$), $p < .001$. Participants with better working memory showed better performance, $\beta = 0.02$ ($SE = 0.01$), $p < .05$, and participants with better auditory short-term memory (with hearing acuity partialled out) also showed better performance, $\beta = 0.06$ ($SE = 0.02$), $p < .01$. Performance improved over blocks, which suggests adaptation over exposure time, $\beta = 0.09$ ($SE = 0.02$), $p < .001$. The amount of improvement over blocks was modified by vocabulary knowledge and selective attention: Participants with better vocabulary knowledge improved more over blocks, $\beta = 0.49$ ($SE = 0.17$), $p < .01$, and participants with poorer selective attention improved less over blocks, $\beta = -2.37$ ($SE = 0.71$), $p < .001$.

Response time analysis

Within each data set (the standard-Dutch practice set and the novel-accent data set), response time analysis was restricted to correct responses that were given within three standard deviations from the mean. Response times (measured from video onset) were log-transformed to make the data distribution less skewed. As for the accuracy analyses, the best fitting model without individual predictors was established first, and then the individual background measures were added.

Standard-Dutch practice set. As in the accuracy analyses, we restricted the analysis to the last 13 practice trials (and discarded the first five as being true practice trials). Within this data set, we evaluated the effects of the variables modality group, correct response (statement being true or false), and of the numerical predictors trial and duration of each video, and of any possible interactions. The best fitting model showed an effect of trial number—speeding up of responses over trials: $\beta = -0.005$ ($SE = 0.001$), $p < .001$. As can be expected, statements with longer video durations elicited longer response times, $\beta = 0.0003$ ($SE = 0.00005$), $p < .001$.

Individual background measures were then added as covariates, and interactions between background measures and modality were investigated. The best fitting model showed that responses generally became faster over trials, $\beta = -0.005$ ($SE = 0.001$), $p < .001$. Additionally, longer video clips elicited longer RTs, $\beta = 0.0003$ ($SE = 0.00005$), $p < .001$. Participants with poorer hearing generally had marginally *slower* RTs, $\beta = 0.004$ ($SE = 0.002$), $p = .06$, whereas participants with better working memory had *faster* response times, $\beta = -0.003$ ($SE = 0.001$), $p < .05$. The response time analysis also showed an interaction between modality and hearing acuity, suggesting that participants with poorer hearing benefited more from the audiovisual modality, $\beta = -0.007$ ($SE = 0.003$), $p < .05$.

Novel-accent performance. Within this data set, we analysed the effects of the same variables mentioned for the accuracy analysis (and their interactions). The best fitting model showed that "true" statements elicited faster responses, $\beta = -0.12$ ($SE = 0.03$), $p < .001$. This advantage of true statements over false statements, also seen in the accuracy analyses, may be due to context priming within the true sentences, despite the relatively poor sentence intelligibility (e.g., Aydelott & Bates, 2004; Sheldon, Pichora-Fuller, & Schneider, 2008). Responses became faster over blocks, $\beta = -0.008$ ($SE = 0.001$), $p < .001$, which indicates adaptation. Additionally, video trials with a longer duration elicited longer RTs than shorter ones, $\beta = 0.0002$ ($SE = 0.00002$), $p < .001$. There was no effect of modality on RTs, nor did it interact with any of the other variables.

Then the background measures were added and were tested for their interaction with modality and block. The resulting best fitting model showed no effect of modality on RTs, but there were significant effects of correct response—"true" statements eliciting faster responses than "false" statements: $\beta = -0.12$ ($SE = 0.03$), $p < .001$—and of trial block—faster responses over the course of the experiment: $\beta = -0.008$ ($SE = 0.001$), $p < .001$. Duration of each video clip affected response time with longer clips eliciting slower RTs relative to onset, $\beta = 0.0002$ ($SE = 0.00002$), $p < .001$. Individual predictors for general response speed included hearing acuity, age, vocabulary knowledge, and attention-switching control. Participants with poorer hearing generally had longer RTs, $\beta = 0.003$ ($SE = 0.001$), $p < .01$, and older participants (with hearing acuity partialled out of age) generally had slower RTs, $\beta = 0.007$ ($SE = 0.003$), $p < .05$. Participants with better vocabulary knowledge generally gave faster responses, $\beta = -0.52$ ($SE = 0.15$), $p < .001$. Unexpectedly, participants with poorer attention-switching control also gave faster responses, $\beta = -0.07$ ($SE = 0.03$), $p < .01$. None of the individual measures interacted significantly with modality or with block.

Discussion

This study was set up to investigate adaptation to a novel foreign-sounding accent in different modality conditions (auditory-only and audiovisual) and to investigate individual abilities associated with successful adaptation. As was found for noise-vocoded speech (Kawase et al., 2009), the availability of visual information was expected to improve processing of and adaptation to the novel accent. The present results showed a clear audiovisual benefit on accuracy performance, but little effect on response speed. It should be noted that response speed is particularly sensitive to differences in processing effort when accuracy is at ceiling, which was not the case in our study. Alternatively, the lack of a modality effect on RTs may be related to the fact that modality condition was a between-subjects factor. Thus, condition effects in RT might have been confounded with participant group effects, despite the fact that the two groups were closely matched on all background measures.

We anticipated visual information to be particularly beneficial for those with poorer hearing, and for those with poorer selective-attention abilities, as we assumed that the comodulation of visual and auditory speech movements would facilitate attending the target speech. No interactions were found between modality and attentional measures, but there were some indications that the audiovisual modality was more beneficial for those with poorer hearing. Even though there was a similar trend in the RTs of the accented materials, only in the standard-Dutch baseline trials were responses of those with poorer hearing sped up more by the audiovisual presentation than those of the better hearing participants. The latter is in line with other results showing that the benefit of combining auditory and visual information increases when auditory-only perception is more difficult (Grant & Walden, 1996; Sumby & Pollack, 1954; Walden et al., 1977).

Importantly, despite the clear modality effect on task accuracy, the audiovisual modality did not clearly modify adaptation. Participants in AV group seemed to have a faster rate of adaptation in the first half of the trials, but the total amount of adaptation over the course of the experiment did not differ between the two participant groups. Several accounts can be proposed for this absence of strong modality effects on adaptation.

First, the relatively weak contribution of visual information may relate to our participant population: The older adults tested here may not have been able to fully benefit from the visual information. Visual sensitivity was not assessed in this study. Visual sensitivity was assessed with a Landolt ring chart as part of a different (later) study, in which 56 of the 66 participants of this study participated again. Out of these 56 participants, only 4 had a (corrected) Landolt-C visual acuity that was not within clinically normal limits (binocular vision), of whom 2 participated in the AV group. This leaves a minority of participants that may have had poorer visual acuity (including these 2, maximally 8 out of the 33 participants of the AV group). However, ageing does not just affect visual acuity, but other visual perceptual processes as well, such as contrast sensitivity and motion perception (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999). Consequently, even with normal or corrected-to-normal visual acuity, older adults have been reported to show poorer visual-only recognition of words and sentences (i.e., speech-reading) than younger adults (Cienkowski & Carney, 2002; Legault, Gagné, Rhoualem, & Anderson-Gosselin, 2010; Lyxell & Rönnberg, 1991; Middelweerd & Plomp, 1987). A replication of the present study with a younger population (with good vision) would therefore be required to investigate this account.

Second, the absence of a strong modality effect on adaptation may be related to the type of degradation of the speech signal that participants had to adapt to: Unlike noise-vocoded speech (Dahan & Mead, 2010; Davis, Johnsrude, Hervais-Adelman, Taylor, & McGettigan, 2005), the difficulty understanding the novel accent is not so much hearing what was actually said, but what the speaker meant to say. In other words, the problem in comprehending accented speech is not reconstructing acoustically *degraded* unclear speech, but overcoming (clear) mismatches or ambiguities between what was actually pronounced and what the speaker intended to say (cf. Rönnberg, Rudner, Foo, & Lunner's, 2008, *ease of language understanding* model, on how mismatches between perceived input and representations in long-term memory trigger more explicit processing). Unlike in the case of degraded speech, where visual information may provide complementary cues to what is being said, audiovisual presentation of the accented speech only confirms the mismatch between pronunciation and stored representation. In the Bayesian model of spoken-word recognition, Shortlist-B (Norris & McQueen, 2008), perceptual evidence for a phoneme is weighed against prior probability of this realization of the phoneme. Exposure to the accent and recognition of some words and sentences will lead listeners to adjust their phonetic categories and thus to alter these prior probabilities (Norris, McQueen, & Cutler, 2003). Given that the way in which the accent deviates from standard Dutch is relatively clear, even to adults with generally mild hearing losses, visual information may have relatively little to add in making listeners change their phonetic categories. Thus, visual information may be less helpful in learning to make these new mappings between acoustic representations of the novel accent and stored representations than in the case of acoustically degraded speech.

A third, related, account of our modality results on adaptation could be that the results may not be general to accent adaptation, but to our specific type of (artificial) accent. Note that the accent used here deviated from standard Dutch only with respect to the vowels, and that vowels are not easily distinguished from visual information. Other accents, also differing from the standard language in consonant pronunciation, would have to be involved to investigate this third account.

This study also investigated which abilities relate to adaptation or perceptual learning in general. Our hypothesis was that memory abilities would be predictive of adaptation, as well as linguistic ability. Memory abilities have been shown to predict first- and second-language acquisition in a host of studies, and both auditory short-term memory and working memory were found to be predictive of overall accent performance in the present study. The working memory measure was associated with efficient processing of one's own language and with processing of the novel accent. Note that not all studies on the link between memory and learning specifically target rate of adaptation or learning over time. Rather, learning is often established as an "end product", defined as, for example, second-language proficiency scores (Service, 1992) for success rate in a cued recall test with paired associates (Gupta & MacWhinney, 1997; Service & Craik, 1993). Our result that novel-accent performance relates to short-term and working memory measures is completely in line with these "end product" results. Nevertheless, some studies have suggested that working memory also affected rate of acquisition of a cognitive skill (Head, Raz, Gunning-Dixon, Williamson, & Acker, 2002; Kennedy et al., 2009). This was not borne out in the present study: There were no indications that memory measures related to the novel-accent adaptation curve over the course of the experimental blocks.

Hearing sensitivity showed a general effect on performance on both the standard-Dutch practice trials and the novel-accent test trials (both accuracy and response speed), but did not relate to adaptation. Our results agree with a recent study on adaptation to real foreign accents (Gordon-Salant et al., 2010). Gordon-Salant, Yeni-Komshian, et al. tested native English-speaking younger and older groups (one group with and one group without hearing loss) on their adaptation to Spanish-accented speech. Their results showed no effects of age or hearing status on adaptation to the foreign-accented sentences. The results from our individual differences analyses extend Gordon-Salant et al.'s study on perceptual adaptation in older adults. We found effects of linguistic ability (more specifically, vocabulary knowledge) and selective attention on adaptation over exposure time for the sentences in the novel accent.

To our knowledge, no previous study has shown an effect of linguistic abilities on perceptual learning. It is not immediately clear how vocabulary knowledge could have aided short-term perceptual adaptation to the unfamiliar accent. It has been suggested that perceptual adaptation is an attention-weighing process in which listeners tune their attentional resources toward task-relevant features of the signal and away from those that are task-irrelevant (Francis, Baldwin, & Nusbaum, 2000; Goldstone, 1998; Golomb et al., 2007; Nosofsky, 1986). Specifically for accented-speech, it has been put forward that this process involves retuning the category boundaries between specific phonemes (Evans & Iverson, 2004; Norris et al., 2003). If one thinks of adaptation to a novel accent as "learning to crack a code", then those with richer vocabularies might be better able to get at the systematicity in the novel accent's deviation from standard Dutch. This linguistic ability to deal with phonological variation in the speech signal would be facilitated by good auditory memory (Baddeley et al., 1998): Rehearsal of what was actually said may facilitate learning how the accent deviates from standard Dutch. Indeed, auditory STM scores and working memory scores correlated significantly with vocabulary scores significantly in our sample (cf. Gathercole, 2006, on how this link is typically strongest during the early stages of acquiring a particular—native or non-native—language).

A similar line of reasoning can be adopted for the relationship between selective attention and adaptation for the accuracy scores. Better ability to pay attention to specific details should facilitate perceptual learning if perceptual learning requires attention-shifting strategies. Likewise, selective attention may help in learning to discard the "false friends" that participants encounter listening to the novel accent. Whenever participants encountered a word form (such as *zaak*) that in standard Dutch is part of a vowel length minimal pair (e.g., *zak* "bag" and *zaak* "store"), participants should discard the immediate mapping (to standard Dutch *zaak)* and go for the poorer matching *zak* instead.

The results showed an unexpected link between attention-switching control and response speed: Participants with poorer attention-switching abilities showed faster response times. The mechanism behind this association is unclear. A rather speculative account could be that listeners with poorer attention switching are better able to focus their attention on the task. Since we did not find a link between attention-switching control and accuracy, it would be difficult to argue that these participants traded accuracy for speed. Further experiments are required to further explore this relationship.

Finally, we found an effect of age on response speed for the accented sentences, even after hearing loss had been partialled out. Age effects are fairly common in speeded tasks (e.g., Laurienti, Burdette, Maldjian, & Wallace, 2006; Van der Lubbe & Verleger, 2002), particularly in choice reaction time tasks (Kok, 2000; Salthouse, 2000; Yordanova, Kolev, Hohnsbein, & Falkenstein, 2004). This age effect could be anything not captured by the selection of individual ability measures, ranging from age effects on auditory processing (not captured by hearing thresholds) to age effects on decision criteria in speeded choice responses (cf. e.g., Ratcliff, Thapar, & McKoon, 2006).

In short, our results suggest that audiovisual presentation may facilitate initial adaptation to novel-accented speech, relative to auditory-only presentation. More research is needed to investigate whether the lack of robust audiovisual enhancement on adaptation should be attributed to our older participant sample or to the specific speech condition participants had to adapt to here. Further, memory measures were found to be associated with efficient processing of the novel accent. Amount of adaptation over the course of exposure specifically related to attentional ability and vocabulary knowledge. These combined results highlight the importance of memory, attention, and linguistic knowledge for perceptual learning and adaptation in speech processing.

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APPENDIX

Stimulus sentences

Table A1. *True (test) sentences (only presented in the novel accent)*

	Standard Dutch	*Novel accent*	*English translation*
1.	Moeders zijn altijd vrouwen	Mudders zeen aalteed vroewen	Mothers are always female
2.	Krukjes zijn van hout	Kruukjes zeen vaan hoet	Foot stools are made of wood
3.	Zomers is het vaak warm	Zommers ies het vak waarm	It is often warm in summer
4.	Druiven worden gebruikt voor wijn	Druuven woorden gebruukt vor ween	Grapes are used for wine
5.	Meloenen zijn rond	Melunnen zeen roond	Melons are round
6.	Ratten hebben tanden	Raatten heebben taanden	Rats have teeth
7.	Nonnen dragen een habijt	Noonnen draggen ‘n habbeet	Nuns wear a habit
8.	Televisies staan in de woonkamer	Telleffissis stan ien de wonkammer	TV sets are found in the living room
9.	Horloges geven de tijd weer	Hoorlogges geffen de teed wer	Watches display the time
10.	Paarden hebben een staart	Parden heebben ‘n start	Horses have tails
11.	1Bijen vliegen rond op zoek naar voedsel	Beejjen vliggen roond oop zuk nar vudsel	Bees fly around searching for food
12.	Kapiteins voeren het bevel op schepen	Kaapitteens vurren het beffeel oop scheppen	Captains are in charge of ships

(*Continued overleaf*)

Table A1. Continued.

	Standard Dutch	*Novel accent*	*English translation*
13.	Presidenten werken in de politiek	Pressideenten weerken ien de pollittik	Presidents work in politics
14.	Monniken wonen in een klooster	Moonnieken wonnen ien 'n kloster	Monks live in a monastery
15.	Messen worden gebruikt als keukengerei	Meessen woorden gebruukt aals kuukkengeree	Knives are used as kitchen utensils
16.	Lepels worden gebruikt voor het eten van soep	Leppels woorden gebruukt vor het etten vaan sup	Spoons are used for eating soup
17.	Schuurtjes worden gebruikt voor opslag	Schurtjes woorden gebruukt vor oopslaag	Sheds are used for storage
18.	Aardappels worden geschild	Ardaappels woorden geschield	Potatoes need to be peeled
19.	Sloffen worden gemaakt in een fabriek	Slooffen woorden gemakt ien 'n fabbrik	Slippers are made in a factory
20.	Heggenscharen worden in de tuin gebruikt	Heeggenscharren woorden ien de tuun gebruukt	Hedge clippers are used in the garden
21.	Olifanten zijn levende wezens	Olliffaanten zeen leffende wessens	Elephants are living creatures
22.	Tafels zijn meubels	Taffels zeen mubbels	Tables are furniture
23.	Stoelen zijn om op te zitten	Stullen zeen oom oop te zietten	Chairs are meant to sit on
24.	Auto's gebruiken benzine	Oetos gebruukken beenzinne	Cars use petrol
25.	Kakkerlakken zijn insecten	Kaakkerlaakken zeen ienseekten	Cockroaches are insects
26.	Dolfijnen zijn zoogdieren	Doolfeennen zeen zogdirren	Dolphins are mammals
27.	Hamers zitten in de gereedschapskist	Hammers zietten ien de geretschaapskiest	Hammers can be found in tool chests
28.	Ministers zitten in de regering	Mieniesters zietten ien de reggerrieng	Ministers are part of the government
29.	Giraffes hebben een lange nek	Girraaffes heebben 'n laange neek	Giraffes have long necks
30.	Politieagenten lopen op straat	Pollitti-aggeenten loppen oop strat	Police officers walk the streets
31.	Mensen dragen sokken aan hun voeten	Meensen draggen sookken an huun vutten	People wear socks on their feet
32.	Sommige mensen hebben honden als huisdieren	Soommiege meensen heebben hoonden aals huusdirren	Some people keep dogs as pets
33.	De meeste vrachtwagens rijden op diesel	De meste vraachtwaggens reeden oop dissel	Most trucks run on diesel
34.	Spanje is een land in Europa	Spaanje ies 'n laand in Urroppah	Spain is a country in Europe
35.	Een paard heeft vier benen	'n Pard heft vir bennen	Horses have four legs
36.	Beweging is goed voor je gezondheid	Bewegging ies gut vor je gezoondheed	Exercise is good for your health
37.	Een minuut heeft zestig seconden	'n Minnut heft zeestig secoonden	A minute has sixty seconds
38.	Bier bevat alcohol	Bir bevaat aalcohool	Beer contains alcohol
39.	Amerikanen hebben op de maan gelopen	Ammerrikkannen heebben oop de man geloppen	Americans have walked on the moon
40.	Sommige mensen drinken koffie met suiker	Soommiege meensen drienken kooffih meet suuker	Some people have their coffee with sugar

Table A2. *False (test) sentences (only presented in the novel accent)*

	Standard Dutch	*Novel accent*	*English translation*
41.	Bisschoppen ademen door kieuwen	Biesschooppen addemen dor kiwwen	Bishops breathe through gills
42.	Tafels bouwen dammen in de rivier	Taffels boewwen daammen ien de riffir	Tables build dams in the river
43.	Otters dragen kleren	Ootters draggen klerren	Otters wear clothes
44.	Blikopeners dragen zware vrachten	Bliek-oppeeners draggen zwarre vraachten	Can openers carry heavy loads
45.	Druiven eten veel vis	Druuven etten vel vies	Grapes eat a lot of fish
46.	Chirurgen groeien aan planten	Chirruurgen grujjen an plaanten	Surgeons grow on plants
47.	Bevers groeien in een moestuin	Beffers grujjen ien 'n mustuun	Beavers grow in a vegetable patch

(*Continued overleaf*)

Table A2. Continued.

	Standard Dutch	*Novel accent*	*English translation*
48.	Wortels hebben een beroep	Woortels heebben ‘n berup	Carrots have a profession
49.	Bromfietsen hebben een snavel	Broomfitsen heebben ‘n snaffel	Mopeds have a bill
50.	Slagers hebben een staart	Slaggers heebben ‘n start	Butchers have a tail
51.	Mieren zijn van hout	Mirren zeen vaan hoet	Ants are made of wood
52.	Vlinders komen van schapen	Vlienders kommen vaan schappen	Butterflies come from sheep
53.	Hamers kruipen op hun buik	Hammers kruuppen oop huun buuk	Hammers crawl on their stomach
54.	Auto’s kunnen goed zwemmen	Oetos kuunnen gut zweemmen	Cars can swim well
55.	Tantes kunnen in winkels gekocht worden	Taantes kuunnen ien wienkels gekoocht woorden	Aunts can be bought in shops
56.	Kroketten kunnen koppig zijn	Krookeetten kuunnen kooppieg zeen	Croquettes can be stubborn
57.	Asperges kunnen ver vliegen	Aaspeerges kuunnen veer vliggen	Asparagus can fly far
58.	Messen zijn eetbaar	Meessen zeen etbar	Knives are edible
59.	Biefstukken moeten lang studeren	Bifstuukken mutten laang studderren	Steaks need to study long
60.	Wijnflessen rijdeno p de weg	Weenfleessen reedden oop de weeg	Wine bottles drive on the road
61.	Architecten worden verkocht door slagers	Aargitteekten woorden verkoocht dor slaggers	Architects are sold by butchers
62.	Politieagenten hebben een kurk	Pollittih-aggeenten heebben ‘n kuurk	Police officers have a cork
63.	Heggenscharen zijn altijd vrouwen	Heeggenscharren zeen alteed vroewen	Hedge clippers are always female
64.	Ezels zijn deel van de familie	Essels zeen del vaan de faamillih	Donkeys are part of the family
65.	Giraffes zijn fruit	Girraaffes zeen fruut	Giraffes are fruit
66.	Wetenschappers zijn gefabriceerde goederen	Wettenschaappers zeen gefabbricerde gudderen	Scientists are manufactured goods
67.	Beren zijn gefrituurd	Berren zeen gefritturd	Bears are fried
68.	Ganzen zijn groenten	Gaanzen zeen grunten	Geese are vegetables
69.	Ministers worden in een oven gebakken	Mieniesters woorden ien ‘n offen gebaakken	Ministers are cooked in an oven
70.	Olifanten zijn klein	Olliffaanten zeen kleen	Elephants are small
71.	Een kameel is een soort vogel	‘n kammel ies ‘n sort voggel	A camel is a type of bird
72.	Een panter heeft vleugels	‘n paanter heft vluggels	A panther has wings
73.	Een kool is een soort vrucht	‘n kol ies ‘n sort vruucht	A cabbage is a type of fruit
74.	Een boon is zoet	‘n bon ies zut	A bean is sweet
75.	Een overhemd is een lichaamsdeel	‘n offerheemd ies ‘n liechamsdel	A shirt is a part of the body
76.	Een schoen heeft vingers	‘n schun heft viengers	A shoe has fingers
77.	Een aap is een soort vis	‘n ap ies ‘n sort vies	A monkey is a type of fish
78.	Een boor is een muziekinstrument	‘n bor ies ‘n muzzik-ienstrummeent	A drill is a musical instrument
79.	Een viool is een werktuig	‘n vij-jol ies ‘n weerktuug	A violin is a tool
80.	Een kip kan goed gitaar spelen	n kiep kaan gut gitar spellen	A chicken can play the guitar well

Table A3. *Practice sentences (only presented in standard Dutch: First nine sentences are true; last nine are false)*

	Standard Dutch	*Novel accent*	*English translation*
81.	Baksteen is een goed materiaal voor gebouwen	Baaksten ies ‘n gud matterrial vor geboewen	Brick is a good material for buildings
82.	Boekhouden is een beroep	Bukhudden ies ‘n berrup	Bookkeeping is a profession
83.	Juli is een zomermaand	Jullih ies ‘n zommermand	July is a summer month
84.	Een step is makkelijk te besturen	‘n steep ies gemaakkeleek te besturren	A scooter is easy to drive
85.	Een vrachtwagen heeft een motor	‘n vraachtwaggen heft ‘n motter	A lorry has an engine
86.	Een krukje is een soort meubel	‘n kruukje ies ‘n sort mubbel	A foot stool is a piece of furniture

(*Continued overleaf*)

Table A3. Continued.

	Standard Dutch	*Novel accent*	*English translation*
87.	Een wortel is knapperig	‘n woortel ies knaabberieg	A carrot is crunchy
88.	Een smaragd is een edelsteen	‘n smaaraagd ies ‘n eddelsten	An emerald is a precious stone
89.	De hoofdstad van Frankrijk is Parijs	De hofdstad vaan Fraankreek ies Parrees	The capital of France is Paris
90.	Lammetjes kunnen goed vliegen	Laammetjes kuunnen vliggen	Little lambs can fly
91.	Flessen hebben een diploma	Fleessen heebben ‘n dipplommah	Bottles have a certificate
92.	Witlof moet lang studeren	Wietloof mut lang studderren	Chicory has to study long
93.	Krukjes worden gebruikt voor wijn	Kruukjes woorden gebruukt vor ween	Stools are being used for wine
94.	Moeders vliegen rond op zoek naar voedsel	Mudders vliggen roond oop zuk nar vudsel	Mothers fly around in search of food
95.	Vlinders zijn eetbaar	Vlienders zeen etbar	Butterflies are edible
96.	Mieren werken in de supermarkt	Mirren weerken ien de suppermaarkt	Ants work in the supermarket
97.	Slakken gaan uit dansen	Slaakken gan uut daansen	Snails go out dancing
98.	Sinaasappels kunnen diep duiken	Sinnassaappels kuunnen dip duukken	Oranges can dive deeply