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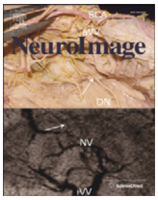

Does experience in talking facilitate speech repetition?

Linda I. Shuster [a,b,*], Donna R. Moore [a], Gang Chen [c], Dennis M. Ruscello [a], William F. Wonderlin [d]

[a] *Department of Speech Pathology and Audiology, 805 Allen Hall, West Virginia University, Morgantown, WV 26506, USA*
[b] *Center for Advanced Imaging, 805 Allen Hall, West Virginia University, Morgantown, WV 26506, USA*
[c] *Scientific and Statistical Computing Core, National Institute of Mental Health, National Institutes of Health, Bethesda, MD 20892, USA*
[d] *Department of Biochemistry, 1 Medical Center Drive, P.O. Box 9142, West Virginia University, Morgantown, WV 26506, USA*

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ABSTRACT

Speech is unique among highly skilled human behaviors in its ease of acquisition by virtually all individuals who have normal hearing and cognitive ability. Vocal imitation is essential for acquiring speech, and it is an important element of social communication. The extent to which age-related changes in cognitive and motor function affect the ability to imitate speech is poorly understood. We analyzed the distributions of response times (RT) for repeating real words and pseudowords during fMRI. The average RT for older and younger participants was not different. In contrast, detailed analysis of RT distributions revealed age-dependent differences that were associated with changes in the time course of the BOLD response and specific patterns of regional activation. RT-dependent activity was observed in the bilateral posterior cingulate, supplementary motor area, and corpus callosum. This approach provides unique insight into the mechanisms associated with changes in speech production with aging.

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Introduction

Vocal imitation is one of the earliest abilities that humans display. It is essential for acquiring speech and language, both for the first time and for the acquisition of a second language. Mature speakers routinely and unconsciously imitate various aspects of the speech of others; this has been observed during both structured imitation tasks and in studies of conversation (Fowler et al., 2003; Pardo, 2006). Speech imitation during social interactions has been proposed to serve a variety of functions, and it may drive phonetic changes in language, as well as the acquisition of dialect (*e.g.*, Babel, 2012; Garrett and Johnson, to appear). The ability to quickly imitate the speech of others can be important. During conversation, for example, a speaker might need to quickly imitate some aspects of their partner's speech to maintain the conversational flow. Unfortunately, the quickness of imitation may decrease with aging. Studies of speech and limb function have revealed that motor responses slow with aging (Fozo and Watson, 1998; Mattay et al., 2002; Rodríguez-Aranda and Jakobsen, 2011). Fozo and Watson demonstrated that the reaction times for producing both simple and complex utterances were slower in older speakers (mean age = 74 yrs) than in young adults. Moreover, imaging studies of motor behavior have shown that older adults seem to recruit more brain regions than younger adults when performing limb movements or speaking (Mattay et al., 2002; Soros et al., 2011).

Although seemingly a trivial skill, speech imitation or repetition putatively involves a variety of underlying cognitive processes, including accurately perceiving the stimulus, holding the stimulus in phonological working memory, constructing a motor plan for producing the utterance and executing the plan. The neurological substrate underlying repetition is proposed to involve a bilateral dorsal stream (Hickok, 2009); however, evidence for this comes predominantly from neuroimaging studies involving young adults. Only one neuroimaging study has investigated the speech repetition performance of older adults (mean age = 71 yrs; Soros et al., 2011). Soros and colleagues used functional magnetic resonance imaging (fMRI) to study older and younger adults while they repeated ‘ah’ and ‘pataka.’ They monitored jaw movement as a measure of response latency. Similar to studies of limb movement, older adults demonstrated more areas of activation than younger participants, but there was no difference between older and younger participants with regard to latency and accuracy of response. These data suggest that the older participants were able to achieve the same level of performance as the younger participants, but they required more brain activation to do so. However, the tasks that Soros et al. employed, especially the production of an isolated vowel, are not typical of the everyday use of speech.

In the present study we have brought together three experimental approaches to investigate how changes in the ability of speakers to imitate speech with aging might be related to changes in underlying neural processes. First, we have used an analysis of the distributions of speech response latencies (*i.e.*, reaction time, RT) to obtain a more complete picture of changes in the speed of imitation with aging than can be interpreted from changes in the mean (or median) alone. Second, we recorded overt speech in a magnetic resonance imaging scanner, which enabled us to examine changes in the activity of different regions

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* Corresponding author at: 515 Michigan St. NE, Suite 200, Grand Rapids, MI, USA.
E-mail addresses: shusterl@gvsu.edu (L.I. Shuster), moore.2492@buckeyemail.osu.edu (D.R. Moore), gangchen@mail.nih.gov (G. Chen), Dennis.Ruscello@mail.wvu.edu (D.M. Ruscello), wwonderlin@hsc.wvu.edu (W.F. Wonderlin).

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of the brain that occur in association with word repetition. Third, Yarkoni et al. (2009) estimated the shape of regional response curves using a finite impulse response analysis of fMRI data collected during a variety of behavioral tasks to identify RT-correlated changes in activity in both gray and white matter regions of the brain. We have used an analogous analytical approach for fMRI data collected during a word repetition task to identify regions in which the RT-correlated activity is affected by age and the type of word to be repeated.

An important goal of this study was to determine how the ability of speakers to repeat real words and pseudowords, tasks that are similar to everyday speech, was influenced by age. We included pseudowords because speakers typically encounter and acquire new vocabulary throughout their lifetime, and a speaker's ability to repeat a pseudoword should reflect the ability to repeat a newly encountered word for which they do not know the meaning. We chose to study middle-aged speakers because there are fewer data for this age group compared to the elderly. Moreover, middle-aged speakers are at risk for diseases such as stroke, but are also under financial pressure to continue to work. Thus, normative data regarding brain function in middle-aged speakers could help in the design of treatments for the recovery of speech post-stroke.

In addition to investigating age-dependent changes in word repetition, we also sought to identify regions of the brain in which the level of activity measured by fMRI covaried with response latency. Variability in the RTs for behavioral tasks typically deviates from a Gaussian distribution around an average value, with the addition of a variable degree of skewing of the distribution towards longer RTs. Many investigators have fitted the positively-skewed distributions of RTs with multi-parameter functions (*e.g.*, ex-Gaussian, Weibull, Gamma, ex-Wald) from which putative relationships between the parameters of these functions (*i.e.*, the shape of the distributions) and various motor and cognitive processes underlying a behavioral task have been proposed (reviewed in Luce, 1986; Van Zandt, 2000; Van Zandt, 2002). However, these relationships are complicated. Therefore, rather than choosing among alternative mathematical functions based on an *a priori* assumption about an underlying model for word repetition, we have used the ex-Gaussian function, which is a convolution of an exponential function and a Gaussian function. The ex-Gaussian function is very robust in fitting distributions of RTs, and it can provide insight into changes in skewness and central tendency, albeit in a model-independent manner (Van Zandt, 2002). We also performed an analysis of covariance of the fMRI data to identify regions of the brain in which the RT-correlated component of the activity was significantly affected by age and/or word type. By comparing these results with the effects of age and/or word type on the parameters of an ex-Gaussian function fitted to the distributions of RTs, we could potentially identify regions of the brain in which the level of activity identified by fMRI analysis might be related to specific features of the distributions of RTs. Although this approach does not enable us to demonstrate causal relationships between brain activity and the distribution of RTs, it does represent an important step towards identifying regions of the brain that might play a role in influencing word repetition.

Material and methods

Participants

Participants were 23 healthy adults, 11 young adults (19.11–28.6 yrs., $M = 22.8$, sd $= 2.4$, 1 male) and 12 middle-aged (48.11–68 yrs., $M = 56.5$, sd $= 7.1$, 5 males) with no history of speech, language or neurological problems and who passed a hearing screening at 20 dB for the frequencies 125–4000 Hz. They were all native speakers of English. The younger adults were undergraduate or graduate students. The middle-aged adults' education ranged from 16 to 20 years ($M = 17.8$, sd $= 1.8$) and all were employed in full-time jobs. There was one left-handed participant (middle-aged) as determined by the Edinburgh (Oldfield, 1971). All provided written consent under a protocol approved by the West Virginia University (WVU) Institutional Review Board. Two of the MA participants were unable to repeat all of the words accurately (including the real words) because they had difficulty hearing them, even though they had passed the hearing screening and the stimulus intensity was increased to the maximum. Therefore, the data from these two participants were excluded from the analysis.

Stimuli

The stimuli were 30 four-syllable real words and 30 four-syllable pseudowords that were created by re-arranging the syllables of the real words. The pseudowords were created so as to have the same initial syllable frequency (Celex database Release 2, 1995) and phonotactic probability (Vitevitch and Luce, 1999) as the real words. They were edited to have the same RMS intensity and preceded by the carrier phrase “Do say _____”. The total stimulus length (carrier phrase + word/pseudoword) was 1750 ms. There were also 30 pink noise stimuli of the same duration and RMS intensity as the word stimuli and preceded by the phrase “Don't say _____,” which served as a no-speech control condition.

Experimental design

Participants repeated all of the words/pseudowords aloud one time prior to entering the scanner. They repeated only the word or pseudoword portion of the stimulus (not the carrier phrase). Their responses were recorded on one channel of a digital recorder and the stimuli they heard were simultaneously recorded on the second channel. For the fMRI, we used an event-related design as in Shuster (2009) and Shuster and Lemieux (2005). The fixed interstimulus interval was 12 s. The stimuli were presented in random order in two sessions under the control of the Presentation® software (Neurobehavioral Systems). Forty-five stimuli were presented during each run, 15 of each of the three types (noise, real word, pseudoword) and the duration of each run was 9 min, 20 s. Participants repeated the words/pseudowords aloud immediately upon hearing them, and they were asked to not move their mouths in any way (*e.g.*, lick lips, swallow) in the period immediately following the presentation of the noise stimulus, as well as immediately after the repetition. Again, participants' responses and the stimuli that were presented were recorded digitally. The speech was recorded using an MR compatible microphone (Optoacoustics) mounted to the head coil, and the stimuli were presented over MR compatible Stax ear buds. Participants wore ear muffs over the ear buds. Prior to beginning the actual experimental run, stimuli were presented to each participant while the spiral in/out pulse sequence was running, and the volume was adjusted so that the stimuli were clearly audible. Because the ear muffs fit tightly into the head coil, it was difficult for participants to move their heads; however, in order to minimize head movement as much as possible, a piece of tape was placed across participants' foreheads and attached to each side of the head coil. They were told that if they felt a tug on the tape, this meant they were moving their heads and they should try to avoid this.

Analysis of accuracy of responses

Pseudoword productions that turned the pseudoword into a real word or that were not four syllables were excluded from the analysis, as were any incorrect real word productions, with one exception. In order to create 30 real word and pseudoword stimuli that were matched for initial syllable frequency and phonotactic probability, we had to use both ‘laboratory’ and ‘lavatory.’ If a participant produced ‘lavatory’ in place of ‘laboratory,’ or vice versa, these productions were retained in the analysis. This occurred twice. One middle-aged participant produced ‘lavatory’ when the stimulus was ‘laboratory,’ and one

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