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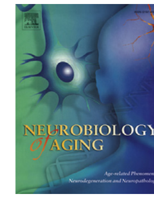

Decline of auditory-motor speech processing in older adults with hearing loss

Muriel T.N. Panouillères [a,b,c,*], Riikka Möttönen [a,d]

[a] Department of Experimental Psychology, University of Oxford, Oxford, United Kingdom
[b] School of Sports Sciences and Human Movement, CIAMS, Université Paris-Sud, Université Paris-Saclay, Orsay, France
[c] UFR Collegium Sciences et Techniques, CIAMS, Université d'Orléans, Orléans, France
[d] School of Psychology, University of Nottingham, Nottingham, UK

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ABSTRACT

Older adults often experience difficulties in understanding speech, partly because of age-related hearing loss (HL). In young adults, activity of the left articulatory motor cortex is enhanced and it interacts with the auditory cortex via the left-hemispheric dorsal stream during speech processing. Little is known about the effect of aging and age-related HL on this auditory-motor interaction and speech processing in the articulatory motor cortex. It has been proposed that upregulation of the motor system during speech processing could compensate for HL and auditory processing deficits in older adults. Alternatively, age-related auditory deficits could reduce and distort the input from the auditory cortex to the articulatory motor cortex, suppressing recruitment of the motor system during listening to speech. The aim of the present study was to investigate the effects of aging and age-related HL on the excitability of the tongue motor cortex during listening to spoken sentences using transcranial magnetic stimulation and electromyography. Our results show that the excitability of the tongue motor cortex was facilitated during listening to speech in young and older adults with normal hearing. This facilitation was significantly reduced in older adults with HL. These findings suggest a decline of auditory-motor processing of speech in adults with age-related HL.

1. Introduction

Aging is often associated with a progressive decline in hearing, also known as presbycusis (Frisina and Frisina, 1997; Ries, 1994; see for review: Cardin, 2016), which leads to difficulties in perceiving speech (Stewart and Wingfield, 2009; Tun et al., 2010; see for review: Humes and Dubno, 2010). However, hearing loss (HL) is not the only factor affecting speech perception deficits in aging. Indeed, older adults with normal hearing (NH) also experience difficulties in understanding speech in adverse listening conditions compared with young individuals (Frisina and Frisina, 1997; Stewart and Wingfield, 2009; Wingfield et al., 2006). Moreover, older adults with hearing deficits do not perceive speech as well as young adults with matching hearing deficits (Dubno et al., 1984; Wingfield et al., 2006). This suggests that an interaction between HL and aging compromise speech understanding. These changes in speech perception skills are associated with alterations in the structure, function, and connectivity of the auditory cortex (see for recent reviews: Cardin, 2016; Peelle and Wingfield, 2016).

In young adults, the articulatory motor cortex is involved in speech perception, together with the auditory cortex (see for reviews: Liebenthal and Möttönen, 2017; Möttönen and Watkins, 2012; Schomers and Pulvermüller, 2016; Skipper et al., 2017). Models of spoken language processing suggest that the dorsal stream serves as an auditory-motor interface. This interface maps speech sounds onto motor representations via neural projections from the superior temporal cortex to the left posterior temporoparietal junction, the left supramarginal gyrus, the left premotor and motor cortex, and the left inferior frontal gyrus (Hickok and Poeppel, 2007; Rauschecker and Scott, 2009; Scott and Johnsrude, 2003). In agreement with this model, neuroimaging studies in young adults have consistently shown activation of the left frontal speech motor network including inferior frontal gyrus (IFG), premotor cortex, and primary motor cortex during speech perception (Adank, 2012; Callan et al., 2010; Du et al., 2014; Hervais-Adelman et al., 2012; Londei et al., 2010; Osnes et al., 2011; Pulvermüller et al., 2006; Skipper et al., 2005; Szenkovits et al., 2012; Wilson

* Corresponding author at: CIAMS Université Paris-Sud, Université Paris-Saclay, Bâtiment 335-Rue Pierre Coubertin, 91405 Orsay Cedex, France. Tel.: +33 0633302288.
E-mail address: muriel.panouilleres@u-psud.fr (M.T.N. Panouillères).

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et al., 2004.) Moreover, accumulating evidence from transcranial magnetic stimulation (TMS) studies has shown that listening to speech enhances the excitability of the articulatory regions of the primary motor cortex (Fadiga et al., 2002; Murakami et al., 2011, 2013, 2015; Nuttall et al., 2016, 2017; Watkins et al., 2003). Modulation of the activity of the articulatory motor areas using TMS influences performance in both demanding speech discrimination tasks and easy word-to-picture matching tasks (Bartoli et al., 2015; D'Ausilio et al., 2009; Meister et al., 2007; Möttönen and Watkins, 2009; Schomers et al., 2015; Smalle et al., 2015). These findings demonstrate that the articulatory motor regions play a causal role in speech processing in young adults. A recent TMS study investigated the effect of disrupting nodes of the dorsal stream on both speech perception and the articulatory motor cortex excitability (Murakami et al., 2015). TMS-induced virtual lesions in the posterior regions of the dorsal stream, including the posterior superior temporal sulcus and the sylvian parietotemporal areas, led to speech perception deficits and reduced facilitation of the articulatory motor cortex in young adults. This shows that disruptions in auditory processing in temporal areas can result in the reduced recruitment of the articulatory motor cortex during speech perception in young adults.

Little is known about the effect of age-related HL and changes in auditory processing at subcortical and cortical levels on speech processing in the articulatory motor system. It can be hypothesized that reduced input from the cochlear to the auditory system and deficits in auditory processing reduce the input to the articulatory motor cortex. We call this the auditory-motor decline hypothesis. This hypothesis is based on the evidence that, in young adults, auditory and motor areas are closely connected and interact with each other from the early stages of speech processing (see, e.g., Liebenthal and Möttönen, 2017; Skipper et al., 2017). Alternatively, it can be hypothesized that the age-related HL and deficits in auditory processing lead to upregulation of the articulatory motor system, which helps maintaining speech perception. We call this the motor compensation hypothesis, as it is based on the assumption that the articulatory motor system has a compensatory role. There is some evidence supporting this hypothesis. Indeed, in a recent neuroimaging study, older adults showed an enhanced activation of the frontal speech motor areas relative to young adults when listening to speech in noise (Du et al., 2016). Moreover, this increased activation correlated with speech discrimination performance as older individuals with stronger activity of the articulatory sensorimotor regions also had a better accuracy in the speech perception task. The authors proposed that the upregulation of speech motor regions compensates for the deficient auditory processing in older adults and allows successful decoding of speech in adverse listening conditions. The older adults who participated in this study had elevated hearing thresholds relative to the young adults and 6 of 16 older adults had mild-to-moderate HL at a frequency relevant for speech perception (up to 4 kHz, Frisina and Frisina, 1997). It is therefore unclear whether the enhanced activation of the speech motor network was caused by aging, HL, or an interaction of both factors.

The aim of the present TMS study was to determine how aging and age-related HL affect the involvement of the articulatory motor cortex during listening to spoken sentences with and without noise. TMS combined with electromyography (EMG) recordings was used to assess excitability of the tongue and hand motor cortex while young and older adults listened to sentences and nonspeech control stimuli. Listening to sentences was expected to enhance excitability in the tongue, but not hand, motor cortex relative to nonspeech stimuli. Older adults were considered to have HL when their hearing threshold was above 25 dB (Schoof and Rosen, 2014) for any of the tested frequencies between 250 Hz and 4 kHZ (Frisina and Frisina, 1997). First, we tested whether aging affected the recruitment of the articulatory motor cortex during speech perception by comparing the excitability of the tongue motor cortex between young and older adults with NH. Second, we assessed the differences in facilitation of the tongue motor cortex when listening to speech between older adults with NH and older adults with HL to test whether age-related HL affects speech processing in the articulatory motor cortex. We had 2 alternative hypotheses regarding the effect of age-related HL on the involvement of the articulatory motor cortex in speech perception: (1) The motor compensation hypothesis predicts that age-related HL will increase the recruitment of the articulatory motor cortex during speech perception, which will compensate for auditory deficits. (2) The auditory-motor decline hypothesis predicts that age-related HL will reduce the recruitment of the articulatory motor cortex during speech perception.

2. Materials and methods

2.1. Participants

A total of 21 young participants and 24 older adults were recruited for the present research. The data of 3 young adults were excluded because of a failure to record tongue motor evoked potential, the behavioral performance on the 0 dB sentence report being below 50% accuracy or the Montréal Cognitive Assessment (MOCA) score being smaller than 26. The data of 3 older adults was also rejected as their score on the MOCA was below 26. Thus, we report the data of 18 young adults (mean age: 21.9 ± 2.9, range: 18–26 years; 10 females) and 21 older adults (mean age: 68.7 ± 3.2, range: 63–74 years; 8 females). Ten older adults had a clinically NH within the speech frequencies (250 Hz–4 kHz), whereas 11 older adults had a HL within the speech frequencies (250 Hz–4 kHz). All participants were right-handed and native English speakers with no known neurological, psychiatric, or language impairment. All participants gave their written informed consent and were screened prior inclusion for contraindications to TMS. Experimental procedures conformed to the Code of Ethics of the World Medical Association (Declaration of Helsinki) and were approved by the Central University Research Ethics Committee (CUREC) at the University of Oxford (CUREC Reference: R45417/RE001).

Participants' musical abilities were evaluated using the training subscale of the Goldsmiths Musical Sophistication Index (Müllensiefen et al., 2014), which is a self-report inventory assessing individual differences in musical sophistication. Musical abilities were assessed because it has been shown that musical training can have a beneficial effect on speech perception in noise, both in young and older adults (see for review: Alain et al., 2014). Depression was evaluated via the Beck Depression Inventory. Participants had minimal to mild depression (min: 0 to max: 19). We controlled for depression because it can lead to cognitive impairments (Mathews and MacLeod, 2005) that could have affected performance on some of the tasks used in the present study such as the Quick Speech-In-Noise (QuickSIN) and the speech report task.

2.2. Experimental design

All subjects received 1 block of single-pulse TMS to the tongue area of left primary motor cortex and 1 block of single-pulse TMS to the hand area of left primary motor cortex as a control site, while listening to clear speech, speech in noise, speech-correlated noise, or white noise (WN). We recorded from the tongue muscle and not from the lip muscle as we did in previous studies, because stimulating the lip area can be challenging for a number of reasons. First, lip stimulation may lead to unreliable motor evoked potentials