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What does successful speech-in-noise perception in aging depend on? Electrophysiological correlates of high and low performance in older adults

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A B S T R A C T

Aging usually decreases the ability to understand language under difficult listening conditions. However, aging is also associated with increased between-subject variability. Here, we studied potential sources of inter-individual differences and investigated spoken language understanding of younger and older adults (age ranges 21–35 and 57–74 years, respectively) in a simulated "cocktail-party" scenario. A naturalistic "stock-price monitoring" task was employed in which prices of listed companies were simultaneously recited by four speakers at different locations in space. The participants responded when prices of a target company exceeded specific values, while ignoring all other companies. According to their individual performance levels three subgroups of participants were composed, consisting of 12 high-performing and 12 low-performing older adults, and 12 young adults matching the high-performing older group. The analysis of the event-related brain potentials indicated that all older adults showed delayed attentional control (indicated by a later P2) and reduced speech processing (indicated by a reduced N400), relative to the younger adults. High-performing older adults differed in increased allocation of attention and inhibitory control (indicated by a stronger P2–N2 complex) from their low-performing counterparts. The results are consistent with the idea of an adjustment of mental resources that could help compensating potential deficiencies in peripheral and central auditory processing.

1. Introduction

Verbal communication under difficult listening conditions is impaired in older adults. This deficit mainly results from age-related changes in cochlear, retrocochlear, and central auditory processing. Besides well-known hearing deficits due to cochlear pathology, declines in supra-threshold binaural processing as well as in spectral resolution impair the listener's ability to understand language in the presence of competing speech or other auditory stimuli (for reviews, Fitzgibbons and Gordon-Salant, 2010; Humes and Dubno, 2010; Humes et al., 2012). Also, losses of temporal precision in the subcortical encoding of sound has recently been shown to result in disadvantages in processing rapid acoustic changes in speech which contribute to the elderlys' difficulties with speech perception (e.g., Song et al., 2011; Anderson et al., 2012, 2013). Moreover, age-related declines in cognitive processes, affecting working memory capacity, inhibitory control, and information processing speed (e.g., Van der Linden et al., 1999) are assumed to play a role in hearing-in-noise difficulties. In particular, auditory working memory has been shown to be an important factor in the neural processing of speech (Kraus et al., 2012), indicating that cognition has a substantial influence on speech perception and verbal communication. In line with this, age-related deficits in speech perception are evident especially under conditions of high mental workload in combination with acoustically demanding listening situations, while differences between older and younger adults are often quite small in simple tasks (Humes, 2007).

Beside these multiple sources of impairments, there is also evidence that older adults can – at least in part – compensate age-related peripheral and central deficits (review: Schneider et al., 2010). Along the lines of "using the brain when the ears are challenged" (Pichora-Fuller, 2009), top-down processing could become more important: When the processing of incoming speech stimuli is decreased due to age-related declines in the auditory system, contextual information, expectations and anticipations related to redundancies in semantic, syntactic, lexical, and phonological cues are used to complete the missing information (Benichov et al., 2012; Pichora-Fuller and Singh, 2006; Burke and

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Shafto, 2008; Pichora-Fuller, 2008; review: Craik, 2007). Furthermore, there is evidence that older adults investigate extra mental resources to adequately process degraded speech information. In line with the decline-compensation hypothesis (Wingfield and Grossman, 2006) neurophysiological studies showed that the older brain strategically recruits additional neural resources to preserve and improve performance (e.g., Peelle et al., 2010; Tyler et al., 2010; Wong et al., 2009). Studies of spoken language processing in multi-talker environments indicated increased activation in working memory and attention-related cortical areas (Wong et al., 2009) as well as increased fronto-central EEG activity (Getzmann and Falkenstein, 2011; Getzmann, 2012) that was positively correlated with behavioral performance. Thus, as has been proposed for younger adults (Obleser and Kotz, 2011), older adults appear to use different strategies for speech comprehension under adverse conditions, one more contextual and facilitatory strategy, and one more resource-allocating and effortful strategy that may be based on increased allocation of processing resources and selective attention. There is evidence, for instance, that cortical mechanisms involved in active listening to speech can affect even cochlear function through the medial olivocochlear efferent system (e.g., Garinis et al., 2011).

A recent study of normal hearing young and middle-aged adults indicated extremely large inter-individual differences in the ability to selectively attend to a relevant source in speech-in-noise perception (Ruggles and Shinn-Cunningham, 2011). These were mainly related to the early sensory encoding of the temporal structure of sounds (Ruggles et al., 2011). In addition, inter-individual differences in auditory ability (such as speech perception) reported in a number of previous studies (e.g., Drennan and Watson, 2001; Surprenant and Watson, 2001; Kidd et al., 2007) have been found to be related to differences in the listeners individual characteristics like age (review: Fitzgibbons and Gordon-Salant, 2010), hearing status (e.g., Best et al., 2010), or general cognitive abilities like working memory (review: Akeroyd, 2008). Given that the inter-individual variability in cognitive performance usually increases in aging (e.g., Hultsch et al., 2002), it would be important to know in which features of speech processing older adults with serious difficulties in speech-in-noise perception may differ from those who do not show deficits relative to younger adults. In particular, regarding the resource-allocating strategy of compensation, the impact of attentional focusing toward a relevant target and the role of inhibition of concurring irrelevant information for successful speech-in-noise perception in aging has to be clarified.

In the present study, we focused on the cortical basis of inter-individual differences in speech-in-noise perception by analyzing behavioral and electrophysiological data of younger and older adults. A naturalistic speech perception task was employed to generate a listening situation where different speakers talk simultaneously, and where listeners have to attend to a relevant information while ignoring concurring irrelevant information. A modified version of the “stock-price monitoring” task (Getzmann and Falkenstein, 2011) was used in which sequences of simulated stock prices were recited by different speakers located at different positions in space. The listeners had to respond to the occurrence of a target company, and to indicate whether its price was above or below a specific value. In order to generate a dynamic auditory scenery, target and non-target information were presented by two male and two female speakers who continuously changed their spatial positions. Thus, the listeners had to separate this auditory scenery into four sources of information. In case the target company occurred, they had to focus attention as quickly as possible on the speaker presenting the target stimulus, while suppressing the processing of irrelevant information by the competing speakers. Auditory free-field stimulation was used to provide the listeners with rich and realistic localization cues (e.g., Getzmann and Lewald, 2010; review: Blauert, 1997). As a baseline condition, the sequences of stock prices were presented by a single speaker, while in the test condition sequences were presented by four speakers simultaneously.

In order to study the cognitive sub-processes of successful speech-in-noise perception in higher age, the total of older participants was (post-hoc) subdivided into a high-performing (Old-High) and a low-performing (Old-Low) group, and the event-related potentials (ERPs) of these two groups were analyzed. ERPs reflect synchronous neuronal activity associated with sensory and cognitive processes making it possible to examine the neural correlates underlying perceptual and cognitive processes. Correlates of early stimulus processing are given by the P1 and N1 deflections. While these components were initially regarded as stimulus-driven and reflecting the automatic processing of sensory input, there is evidence that top-down triggered processes of goal-oriented and top-down allocation of attention affect even the early stimulus processing reflected by P1 and N1 (e.g., Schneider et al., 2012; Wascher and Beste, 2010; Wascher et al., 2009; for review, Eimer (2014)). Correlates of subsequent processing are given by the P2, N2, and N400 deflections. These later ERP components depend even more on the listener's attentional state and reflect controlled processing on a higher level of perceptual and cognitive operations (e.g., Gaillard, 1988): The P2 has been related to processes of stimulus evaluation, indexing some aspects of attentional allocation or stimulus classification (Potts, 2004), and the N2 and N400 are assumed to be correlates of cognitive control and suppression of irrelevant information (Folstein and Van Petten, 2008) and of the processing of language and (potentially) meaningful stimuli (Kutas and Federmeier, 2011).

Neural correlates of good speech-in-noise perception in older adults were investigated by contrasting the ERPs of Old-High and Old-Low groups: Significant differences in the early components would suggest that deficits in sensory encoding and processing play a major role, while differences in the P2, N2, and N400 would suggest deficits in attentional orienting, cognitive control, and language processing, respectively.

In addition, age-related differences in successful speech-in-noise perception were studied by comparing the ERPs of the Old-High group with a third subgroup, consisting of younger participants (Young) that matched the Old-High group in performance. Here it was tested whether high performance of older participants was associated with preservation of processing capacities, enabling the resource-allocating and effortful speech perception strategy to be performed as efficient as by the young, or with age-specific compensation of actual deficits. These compensation mechanisms should be indicated by additional brain activity in the Old-High group, relative to the Old-Low and Young groups. Finally, ERPs of the Old-Low group and the Young group were compared to reveal differences in processing that account for performance differences but not for compensatory effects. Here, any differences observed between the Young and Old-High groups, but not between the Young and Old-Low groups, should be attributable to compensation and not aging. Similarly, any differences observed between the Old-High and Old-Low groups, but not the Young and Old-Low groups, should be attributable to compensation and not performance differences.

2. Material and methods

2.1. Subjects

A total of 48 volunteers took part in the study, consisting of 24 young (12 female, mean age 26.4 years, age range 21–35 years)