Brain & Language 125 (2013) 253–263

Contents lists available at SciVerse ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l

Neurophysiological investigation of phonological input: Aging effects and development of normative data

Annelies Aerts [a,b,*], Pieter van Mierlo [c], Robert J. Hartsuiker [d], Hans Hallez [c,e], Patrick Santens [a,b], Miet De Letter [a,b]

[a] Faculty of Medicine and Health Sciences, Ghent University, De Pintelaan 185, B-9000 Ghent, Belgium
[b] Department of Neurology, Ghent University Hospital, De Pintelaan 185, B-9000 Ghent, Belgium
[c] Medical Image and Signal Processing Group, Department of Electronics and Information Systems, Ghent University – IMinds, De Pintelaan 185, B-9000 Ghent, Belgium
[d] Faculty of Psychology and Educational Sciences, Department of Experimental Psychology, Ghent University, Henri Dunantlaan 2, B-9000 Ghent, Belgium
[e] Department of Industrial Sciences & Technology, College University of Bruges-Ostend, Zeedijk 101, 8400 Ostend, Belgium

ARTICLE INFO

Article history:
Accepted 3 February 2013
Available online 28 March 2013

Keywords:
Mismatch Negativity (MMN)
P300
Phonology
Input
Auditory discrimination
Word recognition
Aging
Neurophysiology
Aphasia

ABSTRACT

The current study investigated attended and unattended auditory phoneme discrimination using the P300 and Mismatch Negativity event-related potentials (ERPs). Three phonemic contrasts present in the Dutch language were compared. Additionally, auditory word recognition was investigated by presenting rare pseudowords among frequent words. Two main goals were: (1) obtain normative data for ERP latencies (ms) and amplitudes (μV) and (2) examine aging influences. Seventy-one healthy subjects (21–83 years) were included. During phoneme discrimination aging was associated with increased latencies and decreased amplitudes. However, a discrepancy between attended and unattended processing, as well as between phonemic contrasts, was found. During word recognition aging only had an impact on ERPs elicited by real words, indicating that mainly semantic processes were altered leaving lexical processes unharmed. Early sensory-perceptual processes, reflected by N100 and P50, were free from aging influences. In future, neurophysiological normative data can be applied in the evaluation of acquired language disorders.

1. Introduction

In order to understand spoken language, it is necessary to complete several phonological stages successfully before proceeding with semantic processing. Phonological stages comprise detection, identification and discrimination of spoken phonemes followed by the recognition of a spoken word as being part of a person's mental lexicon (McClelland & Elman, 1986; Poeppel, Idsardi, & van Wassenhove, 2008). A spoken phoneme is considered as the smallest segmental unit used to obtain meaningful contrasts between utterances (International Phonetic Association, 1999). These units are defined by phonemic contrasts that characterize and distinguish between each phoneme. Three main contrasts that can be identified in Dutch consonants are place of articulation (PoA), manner of articulation (MoA) and phonation of the consonants (voicing).

How are these phonemes and words represented in the brain? The discrimination of spoken phonemes has been linked to the activation of different long-term phoneme-memory traces (Dehaene-Lambertz, 1997; Näätänen et al., 1997). These traces are based on recognition patterns of phonemic contrasts that mature throughout language development and are specific to one's native language. Taking into account that spoken words consist of fixed sequences of spoken phonemes and syllables, it can be assumed that the cerebral representation of spoken words is a hierarchically organized structure of simultaneously activated phoneme memory traces. In turn, they can form specific cortical memory traces for words (Näätänen, 2001; Pulvermüller et al., 2001; Shtyrov & Pulvermüller, 2002). These cortical memory traces, both for phonemes and for words, are physically dependent on neuronal cell assemblies which consist of simultaneously firing nerve cells and create an associative network through hebbian learning. These networks have specifically been located in the language dominant left temporal lobe, with the possibility that distinct topographical patterns exist for individual words (Näätänen, 2001; Pulvermüller, 1999; Pulvermüller, Shtyrov, Kujala, & Näätänen, 2004b). Additionally, aging has been associated with a loss of gray matter density (Sowell et al., 2003). This can lead to weakened internal connections within the memory traces, leading to impaired discriminatory abilities (Alexandrov, Boricheva, Pulvermüller, & Shtyrov, 2011). Although, on a behavioral level poorer phoneme discrimination skills in older subjects are not always expressed (Holmes, Kricos,

* Corresponding author. Address: Ghent University – Faculty of Medicine & Health Sciences, Ghent University Hospital - Department of Neurology, De Pintelaan 185 (1K12-IA), B-9000 Ghent, Belgium. Tel.: +32 (0)9 332 49 28.
E-mail address: annelies.aerts@ugent.be (A. Aerts).

0093-934X/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.bandl.2013.02.010

& Kessler, 1988). However, auditory comprehension abilities in elderly people are very often disturbed. Problems with complex language stimuli arise and more contextual information during word recognition is needed due to a decline in auditory sensitivity, deficits in temporal processing and/or general cognitive slowing (e.g. disturbed semantic memory recruitment) (Benichov, Cox, Tun, & Wingfield, 2012; Schneider, Daneman, & Pichora-Fuller, 2002; Sommers et al., 2011).

The neurophysiological correlates of phoneme discrimination and word recognition can be investigated by means of event-related potentials (ERPs). For phoneme discrimination the pre-attentive Mismatch Negativity (MMN; Näätänen, Gaillard, & Mäntysalo, 1978) and the attentive P300 potential (Sutton, Braren, Zubin, & John, 1965) can be applied. In addition, the lexical/semantic N400 potential is considered as a measure for both word recognition and word comprehension (Kutas & Hillyard, 1980). The MMN and P300 are typically elicited by dedicated oddball paradigms in which a frequent stimulus is interspersed by an infrequent, target stimulus. The N400 can also be elicited by such a task although it is more common in priming and violation paradigms (Kutas & Federmeier, 2011). The MMN is a relatively small negative potential, which occurs between 150 and 250 ms after stimulus onset even when the subject is not attending to the stimulus. This ERP is associated with the outcome of an automatic and preconscious auditory discrimination process (Näätänen, Paavilainen, Rinne, & Alho, 2007). The positive P300 potential, on the other hand, is quite large, appears approximately 300 ms after infrequent stimulus presentation and is more related to working memory, context updating, attention resources and stimulus classification and categorization (Linden, 2005; Polich, 2004). Finally, the N400 is a negative deflection around 400 ms after stimulus presentation and is mostly linked to processes such as lexical access and semantic or contextual priming and integration (Giaquinto, Ranghi, & Butler, 2007; Kutas & Federmeier, 2000). Event-related potentials emerging as a response to the frequent stimulus both in attended and unattended conditions are the negative N100 potential around 100 ms and the positive P200 potential around 200 ms (often called the N100–P200 complex). They are associated with sensory-perceptual processes and intermediate stages of auditory feature analysis, detection and identification and are fully separable from the MMN, P300 or N400 (Cooper, Todd, McGill, & Michie, 2006; Näätänen, Kujala, & Winkler, 2011).

Several studies have been conducted to unravel the effects of aging on the potentials mentioned above. Generally, non-linguistic stimuli (pure tones differing in frequency and/or duration) have been used and it seems that the pre-attentive MMN has been less affected by age than the attentive P300 potential (Schiff et al., 2008). P300 studies have found decreased amplitudes and prolonged latencies in older individuals compared to younger individuals (Juckel et al., 2012; Kok, 2000; Polich, 2004; Schiff et al., 2008). This pattern was attributed to more difficult and less efficient auditory processing in the elderly (Bertoli, Smurzynski, & Probst, 2005). However, in a study with only small changes between contrasting pure tones equal amplitudes of the P300 across ages have been found, but in combination with fading of the MMN in the older age group (Alain, Mcdonald, Ostroff, & Schneider, 2004). This was interpreted as a greater reliance on controlled processes in elderly people. Amplitude attenuations and peak latency delays of the MMN with increasing age have repeatedly but not consistently been demonstrated in several studies (Cooper et al., 2006; Czigler, Csibra, & Csontos, 1992; Gaeta, Friedman, Ritter, & Hunt, 2002; Kiang, Braff, Sprock, & Light, 2009; Pekkonen et al., 1996). Moreover, a study that has used linguistic stimuli (phonemes differing in voicing and PoA) even indicates that the MMN can be affected in a different way depending on the phonemic contrasts (Csèpe, Osman-Sági, Molnár, & Gósy, 2001). However, this has been established in aphasic patients and has to our knowledge never been confirmed in the context of aging influences. The N400 in the context of lexical access and word recognition has indicated to be unaffected by age, showing no differences in latencies and amplitudes between young and elderly age groups (Giaquinto et al., 2007; Karayanidis, Andrews, Ward, & McConaghy, 1993). Early ERP components, such as the N100 and P200, have displayed distinct effects of aging. The P200 has been one of the very few potentials that more often displays large amplitude increases in the elderly and has been related to inhibition during auditory processing (Crowley, Trinder, & Colrain, 2002). Regarding P200 latencies, conflicting results have described both prolongations and stability through aging (Crowley & Colrain, 2004). The N100 has been less subject to aging effects, although interstimulus interval (ISI) can be an influencing factor with mainly amplitude increases at longer stimulus intervals (Bertoli et al., 2005; Cooper et al., 2006; Czigler et al., 1992; Kisley, Davalos, Engleman, Guinthera, & Davis, 2005).

Combined with behavioral data, ERPs can be of great value in clinical and diagnostic situations. In view of the distinct disturbances of phonemic contrast perception in patients with brain lesions (Csèpe et al., 2001), it is necessary to figure out which kind of phonological input stimuli are the most susceptible to aging and which trends can be observed for phoneme discrimination and word recognition during aging. This is essential before implementing cognitive event-related brain potentials in the evaluation of language-impaired individuals of variable ages.

The current study has two main objectives. Primarily, we want to provide neurophysiological normative data for different age categories for phoneme discrimination and word recognition processes for the evaluation of language disorders and the monitoring of language rehabilitation in aphasia. On that account, it is important to study the effects of the healthy aging brain on these language processes. So, a second aim is to qualitatively map influences of aging (1) on consonant contrast sensitivity of the three different phonemic contrasts naturally present in Dutch, namely PoA, voicing and MoA and (2) on word recognition. It is examined whether there exists a discrepancy between unattended (MMN) and attended (P300) discrimination of phonemic contrasts and whether there is a correlation between neurophysiological and behavioral task results.

2. Methods

2.1. Subjects

Seventy-one healthy subjects, who were mainly recruited from hospital staff and senior club houses, participated in the study. All persons investigated were right-handed, as verified with the Dutch Handedness Inventory (DHI; Van Strien, 1992), except for 1 person who was left handed (score of −10 on DHI). All the participants had Dutch as native language and had normal hearing. None of them had neurological or psychiatric disorders. Prior logopaedic problems, such as speech and language developmental disorders, were excluded by history. At time of testing, none of the participants was on medication. The age of the participants (48 females, 23 males) ranged from 21 to 83 years with an average of 50.18 years (SD ± 14.96) and their mean level of education was 13.94 years (SD ± 2.93). In order to generate normative tables six age categories were created per decade: 20–29 years, 30–39 years, 40–49 years, 50–59 years, 60–69 years and 70 + category. The Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was performed in participants above the age of 70 to ascertain the absence of underlying cognitive decline. Table 1 gives a summary of the number of subjects per age category with MMSE results for the 70+ category. The study was approved by the Ethics Committee