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Temporal processing and context dependency of phoneme discrimination in patients with aphasia

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Abstract

Standard diagnostic procedures for assessing temporal-processing abilities of adult patients with aphasia have so far not been developed. In our study, temporal-order measurements were conducted using two different experimental procedures to identify a suitable measure for clinical studies. Additionally, phoneme-discrimination abilities were tested on the word, as well as on the sentence level, as a relationship between temporal processing and phoneme-discrimination abilities is assumed. Patients with aphasia displayed significantly higher temporal-order thresholds than control subjects. The detection of an association between temporal processing and speech processing, however, depended on the stimuli and the phoneme-discrimination tasks used. Our results also suggest top–down feedback on phonemic processing.

Keywords: Auditory processing; Temporal-order threshold; Phoneme discrimination; Language comprehension; Aphasia

1. Introduction

The processing of temporal information in the speech signal has been investigated explicitly over the last few decades. As speech evolves over time, it contains information on different time scales (Rosen, 1992). In the time domain of about 20–40 ms information about the place of articulation in stop consonants is contained. Formant transitions, characterized as short sound waveforms that change frequency across a time interval of ca. 40 ms vary according to the place of articulation. These spectral changes at the release of the closure depend on the articulatory structure that is used to form the constriction (labial /b/, /p/; alveolar /d/, /t/; velar /g/, /k/) (Stevens, 1998). Moreover, a difference in duration of about 20 ms in the time between the burst and the onset of laryngeal pulsing, defined as the voice-onset time (VOT), distinguishes voiced (/b/, /d/, /g/) from voiceless stop consonants (/p/, /t/, /k/) (Stevens, 1998). In contrast, the time scale of 150–250 ms is assumed to be connected to syllabic and prosodic information (Rosen, 1992). As has been shown, syllable durations are usually around 200 ms long (Greenberg, 1999). This time constant is a characteristic feature across languages and has been assumed to be relevant for perceptual unit formation, i.e., encoding syllables (Poeppel, 2003).

The two temporal windows are embedded in the asymmetric sampling in time (AST) model proposed by Poeppel (2003) which suggests a functional asymmetry in the processing of auditory and speech signals in the time domain. AST suggests that the short temporal window is associated with γ-band activity over the left cerebral hemisphere, whereas the longer temporal window is correlated with θ-band activity over the right hemisphere. Based on psychophysical and physiological research, rhythmic brain activity is thought to provide fundamental temporal-building blocks in sensory and cognitive processing. Magnetoencephalographic recordings (MEG) in humans suggest that 40-Hz activity is involved in the perceptual separation of

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acoustic events over time. These MEG recordings are believed to result from a coherent 40-Hz resonance between thalamocortical loops responsible for binding neural processes involved in perception (Joliot, Ribary, & Llinás, 1994; Llinas & Ribary, 1993; Pöppel, 1997). In addition, a longer temporal integration window in audition of around 150–250 ms has been proposed based on EEG and MEG studies (Näätänen, 1992; Yabe, Tervaniemi, Reinikainen, & Näätänen, 1997).

In the present study, the association between temporal processing in the time range of 20–40 ms and phonemic processing is addressed. Findings indicate that deficits in the processing of rapidly changing signals, i.e. increased thresholds for the detection of temporal order of acoustic stimuli, are often correlated with phoneme-identification and phoneme-discrimination impairments in patients with left-hemispheric lesions to the brain and aphasia, children with specific language impairment and children and adults with dyslexia (e.g., Farmer & Klein, 1995; von Steinbüchel, Wittmann, Strasburger, & Szelag, 1999; Swisher & Hirsh, 1972; Tallal & Piercy, 1973; Wittmann, Burtscher, Fries, & von Steinbüchel, 2004). Based on these associations some authors have suggested that the processing of rapid temporal changes in the speech signal is required for correct phonemic processing (Efron, 1963; Pöppel, 1997; Tallal, 1980; Tallal, 1984; Wittmann, 1999).

Over the last years several diagnostic methods have been developed to assess temporal-processing mechanisms in children (Tallal et al., 1996). Nonetheless, no standard diagnostic tool has been established to assess auditory temporal-order detection in adult patients with aphasia in a clinical setting (Wittmann & Fink, 2004). Temporal-order measurements are usually conducted by presenting two consecutive stimuli and varying the inter-stimulus intervals (ISI). Subjects repeatedly have to indicate the order of the presented stimuli until a perceptual threshold is determined. In different studies stimuli vary concerning their physical properties, duration, and stimulation modes. In the alternating monaural condition, two sounds (e.g., clicks) are presented to the participants, one to the left and the other to the right ear. Subjects have to indicate the sequence of sounds: left-right or right-left. These sounds usually have identical physical properties and are equal in duration (e.g., 1 ms; Berwanger, Wittmann, von Steinbüchel, & von Suchodoletz, 2004; Lotze, Wittmann, von Steinbüchel, Pöppel, & Rönneberg, 1999; Mills & Rollman, 1980). In a binaural stimulation mode, a sound is presented to both ears followed by a second different sound with a certain ISI in between, and the subjects have to indicate the order of the two stimuli. Studies employing binaural tasks commonly use pairs of tones with different frequencies but the presented tones vary in *frequency* and *duration* over different studies (e.g., Hirsh & Sherrick, 1961; Kanabus, Szelag, Rojek, & Pöppel, 2002).

As these behavioural tasks require attention by the subject, they are difficult to conduct in patients with attention deficits. To study auditory discrimination abilities in subjects with attention problems the mismatch negativity (MMN), a component registered in measures of event-related potentials, can be used. It is elicited by discriminable changes in auditory stimulation and its occurrence is not dependent on attention. Studies showed that MMN to non-speech and speech sound discrimination is attenuated or even diminished after left hemispheric lesions (Aaltonen, Tuomainen, Laine, & Niemi, 1993; Ilvonen et al., 2003). These results indicate that MMN can be used to test auditory discrimination abilities in individuals with attention deficits and that it can be employed as an additional measurement to behavioural data in all tested subjects to rule out the influence of cognitive factors.

To compare different measurement procedures, we conducted an earlier study employing different auditory temporal-order threshold measurements in healthy younger and older adults (Fink, 2004; Fink, Churan, & Wittmann, 2005). Results showed that temporal-order thresholds clearly depend on the physical properties of the stimulus. Re-test reliabilities indicate that an increase in the number of temporal-order measurements improves the validity of the measurements, especially with click stimuli, differentiating subjects with and without disturbances in temporal processing. Furthermore, the results indicate that temporal-order measurements with tones are more suitable for clinical intervention studies than measurements with clicks for at least two reasons. First, the re-test reliability for tones is higher than for clicks. This is important in clinical settings, where multiple measurements are difficult to conduct due to time constraints. Second, a significant positive correlation between temporal-order measurements and phoneme-discrimination abilities could only be confirmed for measurements with pairs of tones, pointing to the validity of the procedure for clinical diagnostic purposes. One important objective of the present study was to determine whether the stronger association between temporal-order thresholds obtained with tones and phoneme-discrimination abilities also exists in patients with aphasia.

Not only diagnostic procedures to test for temporal-processing abilities have recently been developed, but also training procedures have been designed to improve the ability to detect the temporal order of acoustic features in the speech signal in subjects with language impairments. Results show that feedback-training in temporal processing abilities can improve phoneme identification in children with language-learning impairments (Merzenich et al., 1996) and in patients with aphasia (von Steinbüchel, Wittmann, & Pöppel, 1996). Moreover, it has been shown, that purely non-linguistic training can improve reading skills in dyslexic children (Kujala et al., 2001). Although the audio–visual stimuli used in this training contained no rapid transitions, enhanced MMN occurred to infrequent order reversals of tone pairs with 40 ms tones after the training. Most of the training procedures, however, use also modified language stimuli with enhanced and extended formant transitions (Rey, De Martino, Espesser, & Habib, 2002; Tallal et al., 1996). In light of the temporal-processing hypothesis, however, training proce-