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Stimulus-focused attention speeds up auditory processing

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ABSTRACT

Stimulus-focused attention enhances the processing of auditory stimuli, which is indicated by enhanced neural activity. In situations where fast responses are required, attention may not only serve as a means to gain more information about the relevant stimulus, but it may provide a processing speed gain as well. In two experiments we investigated whether attentional focusing decreased the latency of the auditory N1 event related potential. In Experiment 1 slowly emerging, soft (20 dB sensation level) sounds were presented in two conditions, in which participants performed a sound-detection task or watched a silent movie and ignored the sounds. N1 latency was shorter in the sound-detection task in comparison to the ignore condition. In Experiment 2 we investigated whether the attentional N1 latency-decrease was caused by a frequency-specific attentional preparation or not. To this end, tone sequences were presented with a single tone frequency or with four different frequencies. N1 latency was shorter in the sound-detection task in comparison to the ignore condition regardless the number of frequencies. These results suggest that stimulus-focused attention increases stimulus processing speed by generally increasing sensory gain.

1. Introduction

It is well-known that stimulus-focused attention improves auditory performance by enabling one to process relevant stimuli more efficiently. Using various paradigms, numerous studies confirmed that attention directed to the sounds enhances and sharpens neural activity already at the subcortical level of the auditory pathway (Frith and Friston, 1996; Giard et al., 1994; Maison et al., 2001; Rinne et al., 2008), as well as in the primary and secondary human auditory cortices (e. g., Giard et al., 1988; Grady et al., 1997; Jäncke et al., 1999; Okamoto et al., 2007; Rif et al., 1991; Rinne et al., 2007; Salmi et al., 2009; Woldorff et al., 1993). In everyday life there are many situations in which the role of attention is not to make a more detailed analysis of a sound possible, but rather to allow fast responses through fast detection of the relevant sounds. Therefore, attentional effects should not only be reflected in enhanced activity, but also in an increase of overall stimulus processing speed. In the psychological literature this notion is known as 'prior entry hypothesis' (Titchener, 1908); which originally states that attended stimuli come into consciousness more rapidly than unattended stimuli. The speeding-up of perceptual, that is, sensory processing as an effect of attention was intensively investigated for more than a hundred years with various paradigms in different sensory modalities. However, evidence supporting the existence of the prior-entry effect, to date, is rather mixed (Di Russo and Spinelli, 1999; McDonald et al., 2005; Schneider and Bavelier, 2003; Schuller, and Rossion, 2001; Seibold et al., 2011; Shore et al., 2001; Spence et al., 2001; Vibell et al., 2007; Yates, and Nicholls, 2009; Zampini et al., 2005; for summary, see Spence, and Parise, 2010). Due to its superior temporal resolution, the method of event related brain potentials (ERPs) is a suitable choice for the investigation of changes in processing speed. In the first experiment we investigated whether auditory processing speed gains were reflected in the latency of the auditory N1 ERP, then in a further experiment we investigated whether the observed effect was due to a frequency-specific attentional preparation or not.

The auditory N1 waveform peaks between 80 and 120 ms after the onset of a tone or a transient auditory event. It is maximally negative on fronto-central leads and often shows a polarity inversion at the mastoids when the electroencephalogram (EEG) is recorded with nose-reference; which suggests that N1 at least in part originates from the auditory cortex (Vaughan and Ritter, 1970; Wolpaw and Penry, 1975; for summary, see Näätänen and Picton, 1987; Giard et al., 1994; and Herrmann and Knight, 2001). Beside this supratemporal, stimulus-specific subcomponent, the N1 waveform includes other (non-specific) subcomponents as well (Giard et al., 1994; Herrmann and Knight, 2001; Näätänen and Picton, 1987; Näätänen and Winkler, 1999; Vaughan and Ritter, 1970; Wolpaw and Penry, 1975). In functional terms, N1 is mainly referred to as an ERP

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correlate of stimulus onset detection (Parasuraman and Beatty, 1980). Moreover, it is usually described as an exogenous ERP component (Alho et al., 1994; Hansen and Hillyard, 1980; Woldorff and Hillyard, 1991; for a summary, see Herrmann and Knight, 2001), because it reacts sensitively to changes in physical stimulus- and stimulus presentation characteristics. For example, it has been demonstrated that the amplitude of the N1 response exhibits stimulus-specific refractoriness (Barry et al., 1992; Budd et al., 1998). Also, when stimulus intensity is increased, N1 amplitude increases while N1 latency decreases (Arlinger, 1976; Conolly, 1993; Pantev et al., 1989; Picton et al., 1977; Roberts et al., 2000; Stufflebeam et al., 1998). A number of studies demonstrated that the N1 wave is sensitive to tone frequency changes, which affects both its amplitude and latency (Crottaz-Herbette and Ragot, 2000; Dimitrijevic et al., 2008; Jacobson et al., 1992; Näätänen et al., 1988; Näätänen and Winkler, 1999; Pantev et al., 1988; Pantev et al., 1995; Roberts and Poeppel, 1996; Salajegheh et al., 2004; Stufflebeam et al., 1998; Tiitinen et al., 1993; Verkindt et al., 1994; Woods et al., 1993; for a review, see Roberts et al., 2000).

Whereas N1 reflects sensory processing which does not require voluntary activation, it is also affected by the participant's attentional state (Herrmann and Knight, 2001). A large number of studies have demonstrated attention-related ERP changes in the time window of the auditory N1 (e. g., Hillyard et al., 1973; Picton and Hillyard, 1974; Hansen and Hillyard, 1980; Näätänen, 1982; Woods et al., 1984; Näätänen and Picton, 1987). Selective attention studies mainly reported an ERP amplitude enhancement for the stimulus presented to the attended ear compared to the physically identical stimulus given to the unattended ear. It has been a highly debated topic whether this amplitude enhancement is genuine (i.e. brought about by the selective enhancement of the N1 generator process) or apparent (i.e. caused by the activation of functionally distinct, but temporally overlapping ERP components; see Alho et al., 1986, 1992, 1994; Giard et al., 1988; Hillyard et al., 1973; Näätänen, 1982; Näätänen et al., 1978; Näätänen and Michie, 1979; Näätänen and Picton, 1987; Rif et al., 1991; Woldorff and Hillyard, 1991; Woldorff et al., 1993).

It seems plausible that attention may lead to faster neural responses, particularly when sounds are difficult to detect. Consequently, attentional effects may be reflected not only in the enhancement of the N1 amplitude, but also in the decrease of the N1 latency. So far, attentional effects on N1 latency have been scarcely reported (e.g., Seibold et al., 2011 found that the latency of the N1 waveform decreased for target oddball sounds as the function of the preceding cue-target foreperiod in a cued oddball discrimination task), and only few studies addressed directly whether the latency of the magnetic counterpart of N1 (N1m) was affected by attention, with mixed results: Mäkinen et al. (2004) found no attention-related effect, while Okamoto et al., 2007 found an attention-related latency decrease for tones presented in band-eliminated noise. The scarcity of positive reports may be rooted in the generally used range of experimental settings, which might not be optimal for the observation of attention-related latency-effects. In most experiments clearly audible sounds are presented, typically at or above 50 dB sensation level (SL, above hearing threshold level). Moreover, sound onsets are sharp: rise times typically range from 2.5 to 20 ms. Whereas these settings make it possible to obtain ERPs with high signal-to-noise ratio, it seems reasonable to assume that such sounds already lead to a temporally highly focused processing response, which does not allow for substantial speed gains through the increased mobilization of attentional resources (see similar arguments by Schwent et al., 1976 for N1 amplitude effects). That is, these stimulus parameters lead to a ceiling-effect: there is virtually nothing to be gained in terms of stimulus detection efficiency by directing more attention to these sounds, because detection-related processes are already maximally engaged (saturated). The goal of the present study was to investigate whether a measurable attentional speed gain could be observed when soft, slowly emerging sound signals are to be detected. We hypothesized that these sounds do not lead to saturated sound-detection responses, and therefore allow for the observation of an attentional processing speed gain. Whereas such sounds are highly atypical in ERP-based auditory research settings, they may often play an important role in everyday life (e.g. listening to whether the baby has woken up in the next room.)

A model describing how a sensory processing speed gain may be reflected by the reduction of N1 latency can be based on the assumption that on the level of individual sound-onset events the latency of N1 elicitation is probabilistic (jittered; Thornton et al., 2007), and the single-sweep N1 latency distribution accumulates the temporal variability of all neural processes which lead to the elicitation of N1. It has been suggested that attention increases the synchronization of neural responses (Friston et al., 1996; Tononi et al., 1998a; Tononi et al., 1998b), which, applied in the context of the auditory N1, suggests that the well-known attentional N1 amplitude enhancement effect is caused at least in part by a decrease in the latency jitter of single-sweep N1 responses, which results in a higher-amplitude N1 in the averaged ERP (Thornton et al., 2007). It should be noted, however, that the reduction of latency-jitter might not be the only cause of the averge amplitude-difference between passive and active conditions: Tiitinen et al. (2005) found that the amplitude difference was present even at the single-trial level. In the present study, we assumed that attention changes the single-sweep N1 latency distribution by allowing an earlier triggering of single-sweep N1s, thereby not only narrowing the distribution, but also shifting its center (mode) closer to stimulus onset (Fig. 1). This should result not only in a higher-amplitude average waveform, but in earlier average peak latency as well.

Importantly, for stimuli with sharp onsets, the magnitude of the latency decrease may be too small, and go unnoticed in the average ERP. If attention synchronizes and speeds up processes which lead to the generation of N1, then the magnitude of the hypothetical latency effect may be increased if the single sweep N1 latency distribution is spread out over time. It is well-known that slow physical changes in sound parameters generally elicit temporally wider and lower-amplitude average N1s than those with fast changes (Kodera et al., 1979; Onishi and Davis, 1968). In Experiment 1 we presented soft tones, and manipulated sound fade-in speeds (rise time), to make potential attention-related decreases in N1 latency observable in the average N1 waveform. Moreover, as described in the model above, attention-related latency-reductions were hypothesized to be more substantial for sounds with longer rise times.

2. Experiment 1

2.1. Methods

Thirteen healthy volunteers reporting normal hearing status (six women, aged 18–26 years, mean 21 years; one left-handed) participated

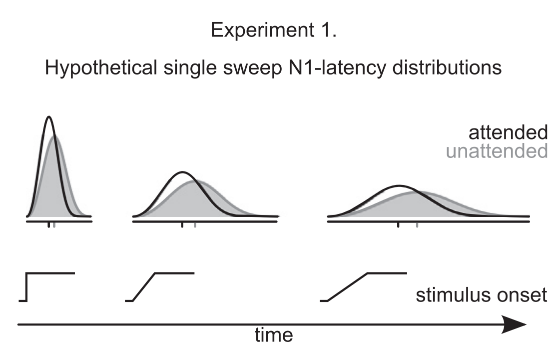

Fig. 1. Hypothetical single-sweep N1-latency distributions (probability density functions) for three rise times when tones are attended or unattended. Tick marks on the horizontal axes indicate the center (mode) of the latency distribution in the attended (black line, white filling) and unattended (gray line, gray filling) conditions. When rise time is short, the latency-distribution difference between the attended and unattended conditions may not be substantial, however, for longer rise times it may bring about larger differences in the N1 peak latencies, which may result in observable latency differences in the average ERP waveforms.