BRAIN RESEARCH 1106 (2006) 164–176

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Research Report

The 'Franssen' illusion for short duration tones is preattentive: A study using mismatch negativity☆

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ARTICLE INFO

Article history:
Accepted 18 May 2006
Available online 10 July 2006

Keywords:
Franssen effect
Precedence effect
Sound localization
Event-related potential
MMN
Auditory illusion

ABSTRACT

When a tone burst is divided into two parts, an onset transient and a sustained tone smoothly fading on, and these parts are delivered to two stereophonically located loudspeakers in a room, a listener gains the impression that the whole sound is coming from the loudspeaker that actually emits merely the transient. Due to this auditory illusion known as the 'Franssen effect' (FE), the physical and the perceived lateralizations of the sustained sound become different. A two-block mismatch negativity (MMN) paradigm was used to investigate the stage of auditory processing at which this segregation would take place. In one block, standard stimuli were 100 ms, 1 kHz tone bursts emitted by one of the loudspeakers, and deviant stimuli were their split version, with the sustained part switched to the other loudspeaker. In the other block, the roles of the two stimuli were swapped. A room acoustics software was used for generating the signals to a headphone. The responses recorded from 10 subjects displayed no MMN, although the same stimuli but without the transients evoked prominent MMNs. This indicated that the mechanism underlying this illusion modifies the neural representation of the stimulus with FE in such a way that it becomes similar to that of the stimulus without FE before reaching the input of the preattentive mechanism indexed by the MMN. Considering the possible relationship of this illusion to the precedence effect and also the relevant electrophysiological findings in the literature, we conclude that the primary auditory cortex is the most plausible site of the mechanism leading to the FE.

1. Introduction

When a burst of tone is split up into two components, one being a sustained tone which fades on and fades off smoothly and the other one consisting of its onset and offset transients, and these components are each emitted by one of a pair of stereo speakers, the tone emitted from one of the speakers is heard as if it is coming from the other one which in fact emits only the transients (see Fig. 1). This illusion is called the Franssen effect (FE), referring to the name of N.V. Franssen, who first described this effect in 1960 in his Ph.D. thesis. He subsequently reported the same effect in a book (Franssen, 1962).

The results of a study by Hafter et al. (1979) showed that, for tones with sufficiently long durations, onsets and offsets were unnecessary for the detection of interaural differences of time or intensity, and that the subject's performance of lateralization of a long duration tone was not notably degraded when its onset and offset transients were masked by noise. In contrast to these findings, which were based on experiments made

☆ Parts of this work were presented in the 6th IBRO World Congress of Neuroscience, 10–15 July 2003, Prague, Czech Republic.

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doi:10.1016/j.brainres.2006.05.075

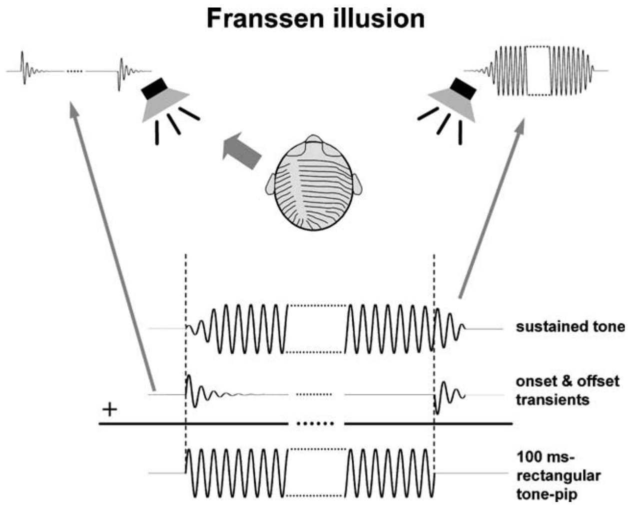

Fig. 1 – A schematic illustration of the Franssen illusion. A rectangular burst of tone (bottom) is split up into two components: Its onset–offset transients and a sustained tone which fades on and fades off smoothly. When these components are each emitted by one of a pair of stereo speakers, the whole sound is heard to be coming from the one on the left, which in fact emits only the transients.

under dichotic listening conditions (with subjects wearing earphones), it was reported by Rakerd and Hartmann (1986) that in a room with even a single acoustical reflection the steady-state sound field of a sine tone fails to provide useful localization information. They also showed that one of the two components to the Franssen illusion is the inability of listeners to localize a pure tone in a room in the absence of an onset, and the other component is the obscuring of modulation cues by the irregular transient response of the room (Hartmann and Rakerd, 1989). It seems, therefore, it is the ambiguity that makes the Franssen illusion possible. Indeed, this illusion fails completely in an anechoic environment, as expected if the effect depends upon the implausibility of steady-state cues in a live room due to reflections. Another piece of evidence supporting the view that the Franssen illusion occurs due to an ambiguity in sound lateralization is the frequency dependence of this illusion. It is best experienced for tones with frequencies between 1000 Hz and 1500 Hz, for which neither interaural time nor level disparities are good localization cues due to the duplex nature of interaural time and level processing (Yost et al., 1997). The observation that the frequencies for eliciting the FE in cats correspond to the frequencies at which cats have difficulty localizing pure tones (Dent et al., 2004) also supports the hypothesis that difficulty in accurately localizing sounds is the basis for this effect.

The fact that the Franssen illusion occurs when there is ambiguity in the perceived direction of a steady tone implies a mechanism which should rely largely upon the spatial cues of the sudden onset rather than those of the steady tone following it. At this point, it is not difficult to see the possible relationship between this effect and another one called the "precedence effect" (PE) (Wallach et al., 1949). Due to the latter effect, which has been studied extensively (for reviews, see Gaskell, 1983; Blauert, 1997; Litovsky et al., 1999), similar sounds arriving in close succession are perceived as a single auditory event ("fusion" or "echo suppression"), and are localized largely by directional cues carried in the first-arriving sound ("localization dominance").

Hartung and Trahiotis (2001) reported recently that peripheral filters, hair cell-based compression, and adaptation could account for various forms of the PE. However, such peripheral mechanisms which could explain this effect for successive transient stimuli may not be suitable for explaining the FE, where a binaural transient stimulus interacts with a binaural steady tone. In a study on the binaural aspects of the precedence effect that may be connected to sound lateralization, Tollin and Yin (2003) demonstrated that, for interaural delays up to about 10 ms, the cats oriented toward the leading source location only, with little influence of the lagging source and reaching an "echo threshold" for delays of 10 ms, where the cats first began to orient to the lagging source on some trials. Therefore, cats should be experiencing the PE phenomenon in the form of "localization dominance," similarly to humans. Based on a number of studies reporting the presence in the cat inferior colliculus of inhibitory connections that would create the PE (Litovsky, 1998; Litovsky and Yin, 1998a,b; Litovsky and Delgutte, 2002), this nucleus might thus appear, at the first glance, to be a candidate for the subcortical site of the FE.

Considering the observations that localization of an impulsive sine tone in rooms is very insensitive to the pulse duration, Rakerd and Hartmann (1986) suggested that binaural inhibition models of the PE must be supplemented by an evaluative component that they termed the "plausibility hypothesis". According to this hypothesis, the listener is supposed to evaluate the interaural cues as if the sounds were heard in a free field. However, certain interaural cues that are impossible in a free field do occur in rooms and assume the status of implausible. They postulate that such implausible cues are discounted by a preconscious process and, in the case of the Franssen illusion, are overridden by the highly plausible localization cues in the onset of the first source.

In a study by Saberi and Perrott (1990), it was concluded that listeners can learn to use the directional cues available in the lagging sound, and that the precedence effect (PE) should result from a cognitive process that is subject to modification from short-term experience. A similar viewpoint was advocated by Damaschke et al. (2005), who observed that the later arriving sound could also evoke an almost full-amplitude wave V in the auditory brainstem response (ABR) and that the subjects with poor performance in the psychoacoustical tasks also produced small cortical mismatch responses. They interpreted these observations as suggesting that the PE is not a result of a poor sensitivity of the peripheral bottom-up processing; it is rather due to some cognitive processes at higher stages of the auditory pathway. In a study by Litovsky et al. (2000), on the other hand, it is reported that the PE cannot be trained away and that the suppressed directional information contained in the lagging source cannot easily be accessed, suggesting a preconscious, probably a hard-wired subcortical mechanism for the lag suppression.