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Newborn infants are sensitive to sound timing

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ABSTRACT

Background

Detecting changes in temporal intervals is important for perceiving music and speech. Relatively long intervals (ca. 300-1500 ms), in the range of preferred tempo and beat perception, were extensively studied in music perception and production (Honing, 2012). Adults and infants are both able to reliably distinguish between different presentation rates as well as noticing changes in the presentation rate (Baruch & Drake, 1997, Baruch *et al.*, 2004).

Shorter time intervals (ca. 10-100 ms) are relevant to the study of expressive timing in music and to prosody and phonology in language (Patel, 2008). Detection of short intervals occurs at the early stages of processing (Cowan, 1984) and it is reflected by the mismatch negativity (MMN; for a recent review, see Näätänen *et al.*, 2011) event-related potential (ERP). Several studies have shown that presenting a stimulus earlier (or later) then expected in an isochronous sequence elicits MMN in adults (Sable *et al.*, 2003) and in (10-month old) infants (Brannon *et al.*, 2004). However, no previous study tested the sensitivity to instantaneous tempo changes in neonates.

Aims

The aim of this study was to test whether newborns detect the onsets and offsets of sound trains as well as instant changes in tempo at presentation rates relevant for music and language perception.

Method

ERPs were recorded from 37 (18 male) healthy, full-term newborn infants during day 1-3 postpartum (7 of the 37 were discarded due to excessive electrical artifacts). The study was approved by the relevant ethics committees (ETT-TUKEB Hungary, Institutional Review Board of ICNP, Hungary)

The stimulus trains consisted of 8 complex tones composed of five harmonics differing only in pitch (F_0), which were taken from the C major scale (C3, D3, E3, F3, G3, A3, B3, C3). Tone duration was 50 ms, with 5 ms rise and 5 ms fall times (raised cosine ramps). 170 trials were presented in two stimulus blocks. For each trial, a pitch was selected randomly (with equal probability; no pitch repetition was allowed). Trials consisted of 8-24 (randomly selected, equal probability) tone repetitions and a silent interval. Tones in the first half of the trial were presented at the "slow" rate (average inter onset interval [IOI]=200 ms), and in the second half at the "fast" rate (average IOI=100 ms), followed by a silent gap (average IOI 1050 ms). See Figure 1a. Time intervals were taken from normal distributions centered on the average with SD=5%. We introduced this timing jitter for higher ecological validity (regarding the trains as a model of speech in a dialogue situation). The amount of jitter remained below the adult JND (Grondin *et al.*, 2011, Quené, 2007). Sounds were presented binaurally via headphones and ear couplers.

EEG was recorded from the F3, Fz, F4, C3, Cz, and C4 locations (10-20 system) against a nose reference with Brain Products V-Amp amplifier (24-bit, sampling 250 Hz). Signals were off-line filtered between 1-30 Hz and epochs from -100 to 500 ms with respect to the tone onset were extracted for each sound. The 100-ms pre-stimulus served as the baseline. Epochs with a voltage change outside the 0.1-100 µV range were rejected from the analyses. Data from infants with less than 100 artifact-free epochs were dropped from the analyses.

The "Start of Train" responses were compared with the "Slow Control" responses, whereas "Change of Rate" and "Omission" responses with the "Fast Control" (see Figure 1a). Control tones were separated from the tempo change and the train onset and offset by 2 or more positions. Average response amplitudes were measured from 40 ms long windows centered on the early and late response maximums found in the difference waveforms (determined by visual inspection). Effects were tested with separate dependent ANOVAs of the structure Stimulus type [Event vs. Control] × Frontality [F vs. C electrode line] × Laterality [left vs. midline vs. right]. Tukey HSD post hoc tests were employed. For more detail on the recording and analysis, see Háden *et al.*, (2009).

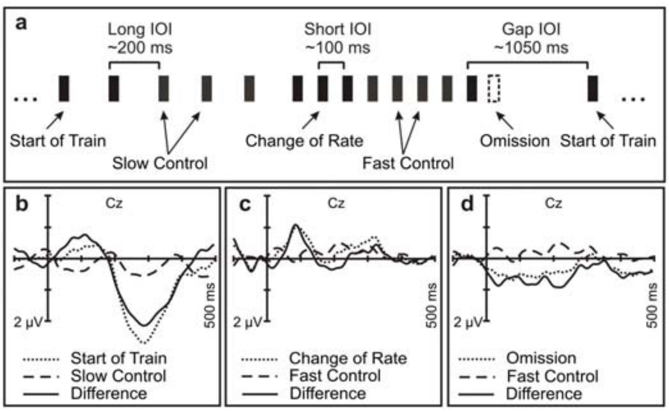

Figure 1. (a) Temporal relations between stimuli in the experimental design. **(b-d)** Grand average ERP responses and difference waves on channel Cz.

Results

Significant differential responses were found for the "Change of Rate" as well as for the "Start of Train" events, whereas the response to "Omission" was only significant for the signals recorded at the central electrodes (C3, Cz and C4).

"Start of Train" vs. "Slow Control" (see Figure 1b): For the early peak [92-132 ms], a significant main effect of Stimulus type, $F(1,29)=8.17$, $p<.05$, $\eta^2=0.20$ was found. For the late peak [268-308 ms], the significant main effects of Stimulus type $F(1,29)=15.03$, $p<.001$, $\eta^2=0.34$, Frontality $F(1,29)=19.40$, $p<.001$, $\eta2=0.40$, and Laterality $F(1.52,44.23)=3.99$, $p<.05$, $\varepsilon=0.76$, $\eta^2=0.12$ were accompanied by significant Stimulus type × Frontality $F(1,29)=10.46$, $p<.01$, $\eta^2=0.27$ and Frontality × Laterality $F(1.64,47.50)=4.73$, $p<.05$, $\varepsilon=0.82$, $\eta^2=0.13$ interactions. The first interaction was due to more positive responses to control stimuli on central channels ($p<.001$)

"Change of Rate" vs. "Fast Control" (see Figure 1c): For the early peak [64-104 ms], significant main effects of Stimulus type $F(1,29)=8.69$, $p<.01$, $\eta^2=0.23$ and Frontality $F(1,29)=9.97$, $p<.01$, $\eta^2=0.26$ were found. On the late peak [300-344 ms], a significant Frontality × Laterality $F(1.94,56.30)=4.18$, $p<.05$, $\varepsilon=0.97$, $\eta^2=0.14$ was observed.

"Omission" vs. "Fast Control" (see Figure 1d): A significant Stimulus type × Frontality interaction was found for the early peak [108-148 ms] $F(1,29)=4.21$, $p<.05$, $\eta^2=0.13$, which was due to the central-only distribution of the difference response ($p<.05$). No significant effects were obtained for the late peak [332-372 ms].

Conclusions

Information encoded in the rate of auditory stimulus presentation and the start and end of sound trains are important in both speech and music (Jaffe & Beebe, 2001; Trehub & Hannon, 2006). The rates tested here are close to the syllabic rate in speech and are somewhat faster than the preferred tempo in music.

The results show that the newborn brain detects onsets and offsets as well as changes in the presentation rate of sound trains. The start of the train stimuli elicited the largest responses, somewhat similar to the responses to novel and white noise deviant stimuli in Kushnerenko *et al*. (2007). These high-amplitude responses may reflect the recruitment of fresh neuronal circuits serving as onset detectors, similar to the auditory N1 in adults (Näätänen & Picton, 1987).

The responses to the "omissions" show that the omitted stimuli were indeed expected after the temporal regularity has been set up. The morphology of the responses differ from the responses elicited by both the start of the train and the change of rate event, as well as from the previous responses reported to stimulus omissions (Winkler *et al*., 2009). Thus it is likely that this event is registered differently from the other temporal violations tested in the study as well as from violations of rhythm (i.e., unlike Winkler et al., the current sequences lacked explicit metrical structure).

We conclude that the mechanisms for detecting auditory events based on timing are already functional at birth making this information available to the infant brain and thus providing an important prerequisite of entering dialogues as well as for music cognition.

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Keywords

Tempo, Interval-discrimination, Onset detection, Offset detection, Development, Neonates; Event-Related Potentials

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