Is Beat Induction Innate or Learned?

Probing Emergent Meter Perception in Adults and Newborns using Event-related Brain Potentials

Henkjan Honing,[a] Olivia Ladinig,[a] Gábor P. Háden,[b] and István Winkler[b]

[a] *Institute for Logic, Language & Computation and Cognitive Science Center Amsterdam, University of Amsterdam, Amsterdam, the Netherlands*

[b] *Institute for Psychology, Hungarian Academy of Sciences, Budapest, Hungary*

Meter is considered an important structuring mechanism in the perception and experience of rhythm in music. Combining behavioral and electrophysiological measures, in the present study we investigate whether meter is more likely a learned phenomenon, possibly a result of musical expertise, or whether sensitivity to meter is also active in adult nonmusicians and newborn infants. The results provide evidence that meter induction is active in adult nonmusicians and that beat induction is already functional right after birth.

***Key words*: rhythm; meter; beat induction; event-related brain potentials (ERPs)**

Introduction

Beat induction, the process in which a regular isochronous pattern (the beat or *tactus*) is activated while listening to music,[1,2] is considered a fundamental human trait that arguably played a decisive role in the origin of music because it can be considered a human-specific and domain-specific skill.[3] However, theorists are divided on the issue of whether this ability is innate or learned. Most authors consider beat and meter perception to be acquired during the first year of life,[3–5] suggesting that parents' rocking their babies to music is the most important factor in developing a sense for beat. We combined behavioral and electrophysiological measures to test whether meter is active in adult nonmusicians. In addition, we studied newborns using a similar paradigm.

Methods

Experiment 1: Adult Study

In the first experiment, we tested whether *meter* (hierarchical representation of a rhythmic sound sequence) emerges in adults with no extensive music training, and whether it is modulated by attention. To this end, reactions to meter violations were assessed using behavioral and electrophysiological measures. Reaction time (RT) and discrimination sensitivity (d') measurements served to characterize active detection of meter violations, whereas event-related brain potentials (ERPs) were used to assess the detection of meter violations under different task loads while the rhythmic sound sequences were not relevant to the participants' task. We presented to nonmusicians weakly and strongly syncopated rhythmic patterns (deviants, D*n*) in a nonsyncopated

Address for correspondence: Henkjan Honing, Cognitive Science Center Amsterdam (CSCA), and Institute for Logic, Language & Computation F (ILLC), University of Amsterdam, P.O. Box 19268, NL-1000 GG Amsterdam, the Netherlands. honing@uva.nl. http://www.musiccognition.nl/newborns/

The Neurosciences and Music III—Disorders and Plasticity: Ann. N.Y. Acad. Sci. 1169: 93–96 (2009).
doi: 10.1111/j.1749-6632.2009.04761.x

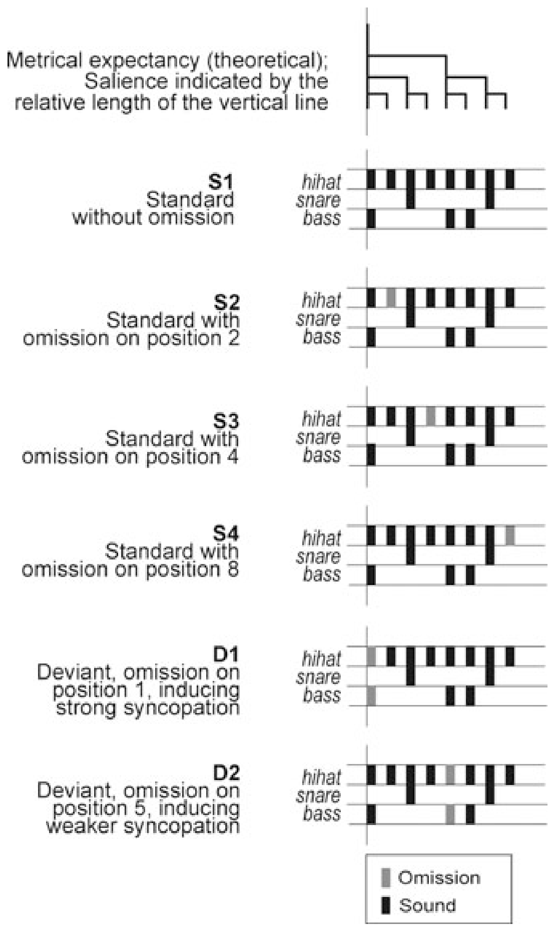

Figure 1. Schematic illustration of the stimuli used in the experiments.

context (standards, S*n*) to probe sensitivity for meter, using behavioral (RT and d' measures of discrimination sensitivity) and ERP measurements. The ERP responses were expected to reveal whether the syncopated deviant patterns violated implicit expectations produced within the auditory system irrespective of the direction of focused attention. Deviations from expected sounds are known to elicit the mismatch negativity (MMN) ERP component with violating stronger expectation reflected by earlier and higher-amplitude responses.[6,7]

Stimuli

Six different sound patterns were constructed (Fig. 1), which were variants of a rhythmic rock pattern (base pattern, S1) with eight grid points. The rhythmic patterns were presented by a typical rock-drum accompaniment using *snare* and *bass*, and with a *hihat* on every grid point. The base pattern and the three variants (containing omissions on the lowest metrical level) were *strictly metrical*; that is, they contained no syncopation or slurred notes throughout the pattern. Together, these four metric patterns formed the set of standard patterns (S1–S4). Two deviants were constructed by omitting events on metrically salient positions in the base pattern, which leads to syncopated patterns: A strongly syncopated pattern was created by omitting the downbeat (D1), and a slightly weaker syncopation by omitting the second most important beat (D2).

Procedure

Experiment 1A: Subjects ($n = 11$) were asked to listen to two blocks of 300 continuously presented trials, and indicate any "deviant" patterns by pressing a button placed in the dominant hand. The two blocks consisted of 90% standard patterns (S1, S2, S3, and S4 with equal probability of 22.5%) randomly intermixed with 5% D1 and 5% D2 patterns.

Experiment 1B: In two conditions the subjects were asked either to press a button at occasional intensity changes in a continuous concurrent noise stream (unattended condition) or ignore all sounds (passive condition) and watch a self-selected muted movie with subtitles. Each condition consisted of 10 blocks of 300 continuously presented trials of rhythmic patterns. The blocks consisted of 90% standard patterns (S1, S2, S3, and S4 with equal probability of 22.5%) randomly intermixed with 10% of D1 or D2 patterns, presented in separate stimulus blocks. One control block for each deviant containing 300 trials of either D1 or D2 patterns was also delivered. Artifact-free ERP responses were extracted from the continuous EEG records, filtered, baseline-corrected, and averaged separately for the different sound patterns. Deviant responses were compared with the responses elicited by the same patterns when they did not

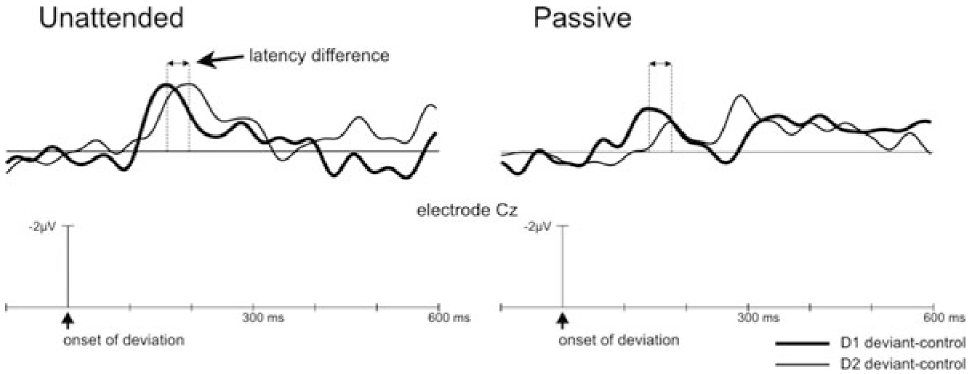

Figure 2. Group-averaged ($n = 11$) deviant-minus-control difference waveforms (thick lines for D1; thin lines for D2 deviants) measured in the unattended (left) and passive (right) conditions. Responses are aligned at the onset of the deviation with the position-related peak latency difference marked by dashed lines and arrows. Strong deviants elicited earlier and, overall, higher-amplitude responses irrespective of the direction of focused attention.

violate the rhythmic regularity of the sequence (control responses).

Results

Discrimination sensitivity was significantly higher for strong (D1) than for weak (D2) deviants ($t = 2.80$, $df = 10$, $P < 0.05$). There was also a tendency toward faster RTs for strong than for weak deviants ($t = 1.85$, $P < 0.1$). Earlier and higher-amplitude MMN responses were elicited by the D1 (most salient) than by the D2 (less salient) deviant, supporting the hypothesis that subjects were sensitive to meter (Fig. 2). These results suggest that meter perception is active in nonmusicians irrespective of the direction of focused attention. [N.B.: An elaborate description of this experiment is published in Ladinig *et al.*[8]]

Experiment 2: Newborn Study

Stimuli

The stimuli were the same as Experiment 1, except that only D1 (Fig. 1) was used as deviant.

Procedure

Sleeping newborns ($n = 14$) were presented with five blocks of 300 continuous trials of rhythmic patterns. The blocks consisted of 90% standard patterns (S1, S2, S3, and S4 with equal probability of 22.5%) randomly interspersed with 10% of D1 patterns. In addition, one stimulus block consisting of 300 trials of D1 patterns was delivered to provide identical-stimulus control for deviant patterns. Artifact-free ERP responses were extracted from the continuous EEG records, filtered, baseline-corrected, and averaged separately for the different sound patterns. Responses elicited by deviant patterns were compared with the responses to the same pattern when it did not violate any regularity (deviant-control) as well as with responses elicited by standard patterns including omitted strokes at nonsalient positions of the rhythmic pattern.

Results

Figure 3 shows that the electrical brain responses elicited by the standard and deviant-control patterns are very similar to each other, whereas the deviant stimulus response obtained in the main test sequence significantly (ranges marked on the figure) differs from them. [N.B.: An elaborate description of this experiment is published in Winkler *et al.*[9]]

Conclusions

The results presented in this paper provide evidence that violating the beat of a rhythmic

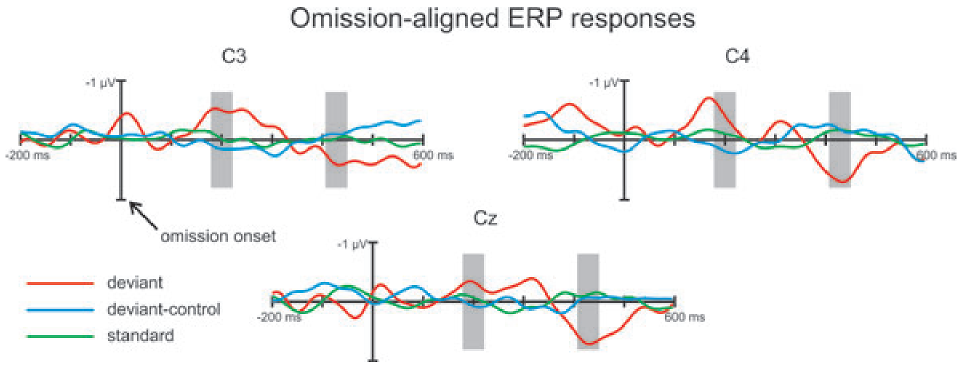

Figure 3. Group-averaged (n = 14) electrical brain responses elicited by rhythmic sound patterns in neonates. Responses to standard (average of S2, S3, and S4; green), deviant (D; red), and deviant-control patterns (D patterns appearing in the repetitive control stimulus block; blue) are aligned at the onset of the omitted sound (compared to the full pattern: S1) and shown from 200 ms before to 600 ms after the omission. Gray-shaded areas mark the time ranges with significant differences between the deviant and the other ERP responses. (In color in *Annals* online.)

sound sequence is detected by adult nonmusicians and newborn infants alike. So it appears that the capability of detecting beat in rhythmic sound sequences is already functional at birth.[9] Beat detection requires only that the length of the full cycle and its onset are represented in the brain. However, it is possible that neonates form a detailed representation of the base pattern. This would allow them not only to sense the beat, but also to build a hierarchically ordered representation of the rhythm (meter induction), as was found for adults.[8] This exciting possibility is an issue for further research.

Acknowledgments

This research was supported by the European Commission's 6th Framework Programme for "Information Society Technologies" (project title: EmCAP Emergent Cognition through Active Perception, contract 013123). We thank János Rigó and István Sziller for supporting the study of neonates at the First Department of Obstetrics and Gynecology, Semmelweis University, Budapest and Erika Józsa Váradiné and Zsuzsanna D'Albini for collecting the neonate and adult ERP data, respectively.

Conflicts of Interest

The authors declare no conflicts of interest.

References

1. Desain, P. & H. Honing. 1999. Computational models of beat induction: the rule-based approach. *J. New Music Res.* **28:** 29–42.
2. Vuust, P., K.J. Pallesen, C. Bailey, *et al*. 2005. To musicians, the message is in the meter: pre-attentive neuronal responses to incongruent rhythm are left-lateralized in musicians. *NeuroImage* **24:** 560–564.
3. Patel, A. 2008. *Music, Language and the Brain*. Oxford University Press. Oxford, UK.
4. Hannon, E.E. & S. E. Trehub. 2005. Metrical categories in infancy and adulthood. *Psychol. Sci.* **16:** 48–55.
5. Phillips-Silver, J. & L.J. Trainor. 2005. Feeling the beat: movement influences infant rhythm perception. *Science* **308**, 1430.
6. Näätänen, R., M. Tervaniemi, E. Sussman, *et al*. 2001. "Primitive intelligence" in the auditory cortex. *Trends Neurosci.* **24:** 283–288.
7. Winkler, I. 2007. Interpreting the mismatch negativity (MMN). *J. Psychophysiol.* **21:** 147–163.
8. Ladinig, O., H. Honing, G. Háden & I. Winkler. 2009. Probing attentive and pre-attentive emergent meter in adult listeners without extensive music training. *Music Percept.* **26**(4): 377–386.
9. Winkler, I., G. Haden, O. Ladinig, *et al*. 2009. Newborn infants detect the beat in music. *Proc. Natl. Acad. Sci. USA* **106:** 2468–2471.