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Without it no music: beat induction as a fundamental musical trait

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Beat induction (BI) is the cognitive skill that allows us to hear a regular pulse in music to which we can then synchronize. Perceiving this regularity in music allows us to dance and make music together. As such, it can be considered a fundamental musical trait that, arguably, played a decisive role in the origins of music. Furthermore, BI might be considered a spontaneously developing, domain-specific, and species-specific skill. Although both learning and perception/action coupling were shown to be relevant in its development, at least one study showed that the auditory system of a newborn is able to detect the periodicities induced by a varying rhythm. A related study with adults suggested that hierarchical representations for rhythms (meter induction) are formed automatically in the human auditory system. We will reconsider these empirical findings in the light of the question whether beat and meter induction are fundamental cognitive mechanisms.

Keywords: rhythm; meter; musicality; event-related brain potentials; attention; cognitive biology

Introduction

It seems a trivial skill: children who clap along with a song, musicians who tap their foot to the music, or a stage full of line dancers who dance in synchrony. In a way it is indeed trivial. Most people can easily pick up a regular pulse from the music or can judge whether the music speeds up or slows down. However, the realization that perceiving this regularity in music allows us to dance and make music together makes it a less trivial phenomenon. Beat induction (BI) might well be conditional to music (i.e., without it no music), and, as such, it can be considered a fundamental human trait that, arguably, must have played a decisive role in how *musicality* evolved.[1]

BI[a] has been the topic of quite a few music perception studies, mostly concerned with the theoretical and psychological aspects of this cognitive skill.[2–5] More recently, the phenomenon has attracted the interest of developmental psychologists,[6] cognitive biologists,[7] evolutionary psychologists,[1] and neuroscientists[8,9] as a skill that is fundamental to music processing.

BI has been argued to be an innate (or spontaneously developing), domain-specific, and species-specific skill.[1] However, with regard to the first issue, scientists are still divided on whether this ability develops spontaneously (emphasizing a biological basis) or whether it is learned (emphasizing a cultural basis). Some authors consider the sensitivity to beat to be acquired during the first year of life, suggesting that the ways in which babies are rocked

[a]The term *beat induction* is preferred here over *beat perception* (and synchronization) to emphasize that a beat does not always need to be physically present in order to be "perceived" (see, e.g., the section on "loud rest"). Furthermore, it stresses that beat induction is not a passive, perceptual process but an active one in which a rhythm evokes a particular regular pattern in the listener. How this process is dependent on attention and/or consciousness, and whether there might be a cognitive and neurological difference between beat induction and meter induction, are topics of current research.

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and bounced in time to music by their parents is the most important factor in developing a sense for metrical structure.[10,11] By contrast, more recent studies emphasize a biological basis, suggesting BI to be specifically tuned to music, for example, studies demonstrating that BI is already functional in young infants as well as two- to three-day-old newborns.[12,13] These recent empirical findings can be taken as a support for a genetic predisposition for BI, rather than it being a result of learning.[14]

In addition, developmental studies suggest that infants are not only sensitive to a regular pulse, but also to meter (i.e., two or more levels of pulse).[15] Thus, it is possible that humans possess some processing predisposition to extract hierarchically structured regularities from complex rhythmic patterns.[16] Research with newborns provides an appropriate context within which to understand more about these fundamental capacities.[17] However, studies addressing hierarchical perception in newborns are still underway. Hence, this review concentrates on how to study beat and meter induction using a mismatch negativity (MMN) paradigm, and addresses some open issues with regard to the cognitive and biological aspects of BI.

Before introducing the MMN paradigm, this paper begins with a theoretical music example illustrating the notion of metrical expectation.

Example: a "loud rest"

In music, an important distinction to be made is that between rhythmic pattern and metrical structure.[18] While rhythm can be characterized as the varying pattern of durations that is physically present in the music, meter involves our perception and, more importantly, anticipation and prediction of such rhythmic patterns. Meter is, as such, a cognitive phenomenon.[19]

The interaction of rhythm and meter, and the role that cognition plays in its perception and appreciation can be illustrated with the phenomenon of *syncopation*. It is often described, rather informally, as "an accent that has been moved forward," or as "a technique often used by composers to avoid regularity in rhythm by displacing an emphasis in that rhythm."[20] To illustrate this, consider the two rhythms depicted in Figure 1. Which of these is a syncopated rhythm?

Figure 1. Which rhythm is syncopated?

A formally trained musician will easily point out the left example, guided by the slur marking a syncopation (literally a "joined beat"). However, performed by a drum computer, these notated rhythms will sound identical. Here the reader is strongly influenced by the notation. When we listen to a rhythm (even if it is simply a series of isochronous clicks, like a clock), we tend to interpret it in a metrical fashion,[21] and hear it as syncopated, or not, depending on our metric interpretation (a time signature in the notation is no guarantee that a listener will perceive the meter as such). This is illustrated by the example in Figure 2.

Western listeners tend to project a duple meter while listening to a rhythm,[22] and hence perceive a syncopation (depicted in the left panel of Fig. 2, i.e., the "loud rest" marked in gray). However, if a listener were to expect, for example, a compound meter—caused by, for instance, a different musical background or listening experience—then the syncopation will disappear altogether. It becomes a "silent rest" (see the right panel of Fig. 2).

An important insight here is that the perception of rhythm should be seen as an *interaction* between the rhythmic pattern (labeled "Rhythm" in Fig. 2) and the listener, who projects a certain meter onto it (labeled "Listener" in Fig. 2), which is induced by that very same rhythm.[23,24] We can therefore use the presence of a syncopation (or "loud rest") as evidence for the presence of a strong metric expectation (be it the result of earlier exposure to music or an inborn preference). This provides an elegant and direct method to probe metrical expectation in listeners, and is the key idea used in the experiments described below.

Using MMN to probe "loud rests"

Electrophysiological measures, such as event-related brain potentials (ERP), are a useful tool in the study of BI and the metrical encoding of rhythm, especially in examining its predictive nature. An informative component of an ERP is the MMN: a negative deflection in the brain signal that occurs if something unexpected happens while listening (even when attention is not directed to the

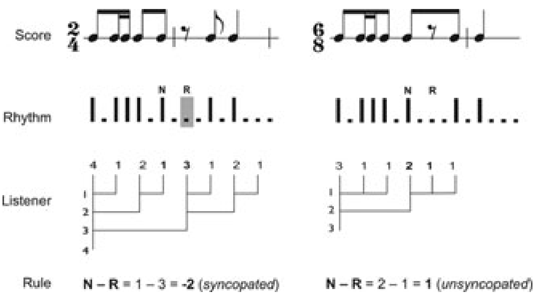

Figure 2. Two possible notations (labeled as "Score") of the same rhythm (labeled as "Rhythm"). In the left example, a metrical tree represents a duple meter, and in the right example it represents a compound meter (labeled as "Listener"). The numbers at the leaves of the metrical tree represent the theoretical metric salience (the depth of the tree at that position in the rhythm). A negative difference between the metric salience of a certain note *N* and the succeeding rest *R* indicates a syncopation. The more negative this difference, the more syncopated the note *N* or "louder" the rest *R* (adapted from Honing).[25]

rhythm).[25] This MMN is generally thought to reflect an error signal that is elicited when incoming sensory information does not match the expectations created by previous information. As such, it can be instrumental in probing a violation in a metrical expectation, such as a syncope or a "loud rest."

Characteristics of MMN

In general, an MMN is elicited when incoming stimuli mismatch the predictions produced by the neural representations of regularities extracted from the acoustic environment (e.g., pitch, duration, timbre, location).[25] Also, abstract information (i.e., one auditory feature predicting another)[26] and omissions can cause an MMN, resulting in an interpretation of the MMN as reflecting the detection of regularity violations as part of a predictive process, rather than just sample matching to sensory memory.[27] More salient deviations trigger earlier (and possibly larger amplitude) negative deflections,[28] and, as such, the MMN can be used as an index to compare metrical expectancies of different strengths. An MMN can be observed when subjects engage in a neutral primary task (e.g., watching a movie; *passive condition*) or when instructed to do an unrelated task (*unattended condition*). However, when participants focus their attention on the stimuli, the MMN is often overlapped by attention- and task-dependent ERP components, such as the P165 and the N2b.[25] This makes measuring ERP in a passive condition especially useful in studying the role of attention and consciousness in perception.[29] Finally, compared to other more recent brain imaging techniques, during measurement, ERP is more tolerant to the subject's physical movements; therefore, it is more suitable for participants whose movements are difficult to regulate and behavioral responses are limited (such as newborns).[30]

One point of concern is what to expect in the case of an omission in an acoustic signal (i.e., a silence or "rest," instead of a note)? An omission means that there is no incoming sound, and the question could then be what is linked to existing regularity representations? While this is still a topic for debate,[31] it is clear that an MMN can be elicited when the interonset intervals in a rhythm are smaller than 150 milliseconds.[32] This constraint on stimulus design has to be balanced with the absolute tempo of a rhythm, to make sure the beat occurs not too far from the preferred tempo rates.[18]

Stimuli and experimental design

An MMN is measured using an oddball design: a sound sequence in which rare sounds (deviants) are intermixed with a common sound (standard). One possible stimulus set to study metrical expectation is shown in Figure 3. It consists of eight different sound patterns, all variants of a base pattern (S1) with eight grid points. The base pattern and the four variants (containing omissions on the lowest metrical level) are "strictly metrical," that is, they contain no syncopation when interpreted in duple meter. Together, these five patterns form the set of standard patterns (S1–S5). Three deviants are constructed by omitting events on metrically salient positions in the base pattern, which lead to syncopated patterns. They are created by omitting a note on position 5 (D1), on position 3 (D2), and on position 7 (D3). According to the theoretical model described in Figure 2 (left panel), the strengths of the deviants are ordered as D1 > D2 > D3, where D1 is predicted to be the "loudest rest" or strongest syncopation, and D3 the weakest.

These stimuli were used in a pilot study (Háden, Honing, and Winkler, in preparation). In a preliminary analysis of the results, an MMN was observed for all three deviants. However, there was only a significant difference between D1 and D3, and the difference wave for D3 was close to zero (i.e., almost no MMN). These results made us wonder about

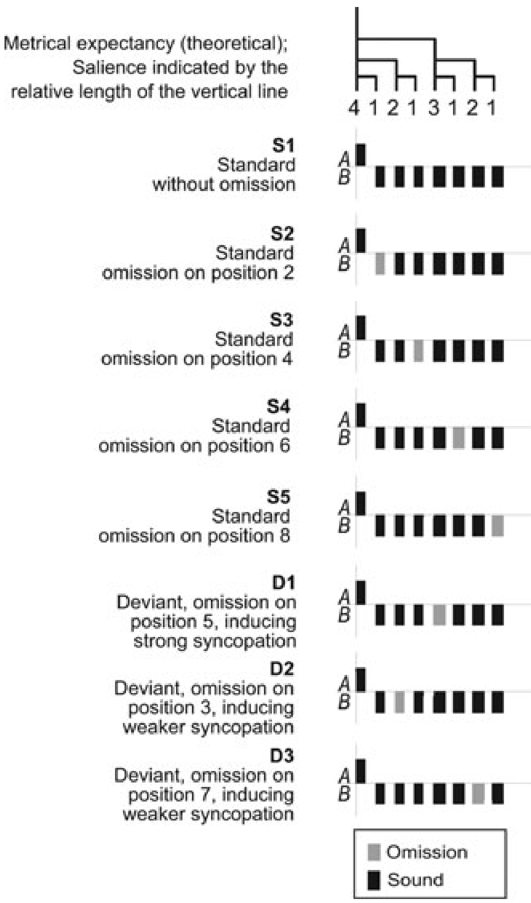

Figure 3. Stimuli as used in a pilot study on metrical expectation. S1–S4 are the standards and D1–D3 the deviants used in an oddball paradigm. Both A and B are percussive sounds, with A being higher-pitched than B, to allow phase alignment.

the relative importance of using more complex (or ecologically valid) stimuli, since in a related study, using more complex stimuli (see Fig. 4), we did get significant effects.[16] In this study, the deviant minus control (deviant – control) difference waveforms showed differences in latency, reflecting a hierarchy in violation of D1 versus D2,[28] as predicted by the theoretical model. However, an analysis of variance (ANOVA) showed a significant interaction between different attention conditions (i.e., passive vs. unattended) and casts some doubt on whether the extraction of a metrical hierarchy is fully automatic.[33]

A similar design using the same stimuli but with only one deviant D1 (because of time constraints) was used with newborns.[13] In that study, we could show that the electrical brain responses elicited by the standard and deviant – control patterns were very similar to each other, whereas the response to D1 differed significantly, providing evidence that (sleeping) newborns can sense the beat. So it appears that the capability of predicting the beat in rhythmic sound sequences is already functional at birth.

Discussion

These studies suggest BI (but possibly not meter induction) to be an automatic process outside of the focus of attention, and they provide evidence that BI is shared among adults and newborns, as such supporting a biological basis.

But how sure can we be that finding an MMN is indeed an evidence for beat and/or meter induction? Are alternative explanations possible?

Because the deviant – control in these studies did not elicit an MMN, we can be sure that the MMN is not a result of the acoustic qualities of the D-pattern *per se*. Furthermore, the response is not simply a result of detecting omissions, otherwise it would show up in the other silent locations as well. Also, the response is not caused by separate representations formed by the three streams (hi-hat, snare, and bass; see Fig. 4): only omissions of the downbeat within the rhythmic context elicited this response (as was checked in a separate experiment with adults).[13]

This leaves the fact that for the deviants, two instead of one element was deleted from the base pattern (see Fig. 4). Although a deviant on its own (deviant – control condition) did not elicit an MMN, along with the fact that all omissions are psychically identical (150 ms of silence) and all stimuli were normalized with respect to amplitude, we can not completely rule out a contribution to the MMN resulting from this manipulation. Introducing an additional pattern with an omission on position 6 (cf. Fig. 4), and including it either as S5 or as D3 in the stimulus set, should reveal this[34] (Bouwer, Háden, van Zuijen, and Honing, in preparation).

Finally, one could wonder to what extent BI is a domain-specific phenomenon, and, as such, represents a predisposition for music. Or is BI a particular instantiation of a general tendency of the brain to recognize mismatches in acoustic signals, including spoken language? However, if such an effect would be found in language, it does not rule out the interpretation that it draws from a fundamental musical trait.[24] So, for now, in the absence of empirical evidence, the domain-specific hypothesis is as likely as the domain-general hypothesis.

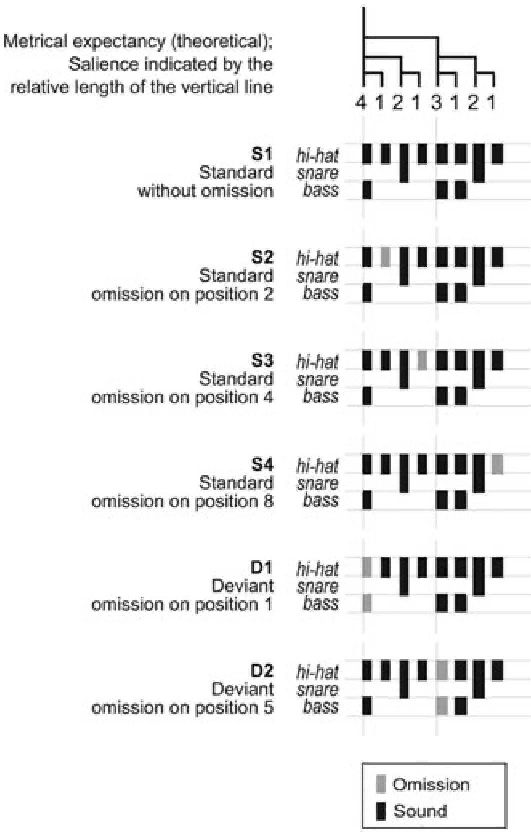

Figure 4. Stimuli as used in an adult and newborn study on metrical expectation. S1–S4 are the standards and D1 and D2 the deviants used in an oddball paradigm. The different percussion sounds are marked as hi-hat, snare, and bass.

Is hierarchy in rhythm innate, learned, or emergent?

As mentioned before, developmental studies suggest that infants are not only sensitive to a regular pulse, but also to meter. While BI requires the length of the full cycle (period) and its onset (phase) to be represented in the brain, it is also possible that newborn infants form an abstract mental representation of the base pattern, for instance, by learning the probabilities of each event in the varying rhythmic pattern or, alternatively, inducing multiple levels of beat. This would allow them not only to sense the beat, but also to build a hierarchical representation of the rhythm (meter induction). It would predict a difference in MMN latency (and possibly amplitude) for a D1 versus a D2, as has been demonstrated in adults.[16] This exciting possibility is an issue for further research. Together with the ongoing work on beat versus meter induction and the role of attention, it will help to address the question whether these hierarchical representations are innate (or at least active at day one), emergent (are they a structural property of the stimuli?), explicitly learned (as a result of musical training), or implicitly learned (as a result of exposure, however brief, to Western music).

Is BI species specific?

As discussed elsewhere,[1] BI might be considered a spontaneously developing, domain-specific, and species-specific skill. With regard to the first aspect, the newborn study provides one single piece of evidence suggesting such early bias. With regard to the second aspect, convincing evidence is still lacking, although it was recently argued that BI does not play a role (or is even avoided) in spoken language.[35] With regard to the final aspect, it was recently suggested that we might share BI with a selected group of bird species,[36,37] and not with a more closely related species such as nonhuman primates.[38] This is surprising when one assumes a close mapping between specific genotypes and specific cognitive traits. However, more and more studies show that genetically distantly related species can show similar cognitive skills, skills that more genetically closely related species fail to show.[39] This offers a rich basis for comparative studies of this specific cognitive function.

Most existing animal studies have used behavioral methods to probe the presence (or absence) of BI, such as tapping tasks[39] or measuring head bobs.[38] It might well be that if more direct electrophysiological measures are used (such as analogs of the MMN in several species),[40] nonhuman primates might indeed also show BI. This is a topic of current research (Honing, *et al.*, in preparation).

Conclusion

BI has been argued to be a spontaneously developing, domain-specific, and species-specific skill.[1,35] Although both (culture-specific) learning and perception/action coupling are relevant in development,[10,11] at least one study shows that the auditory system of a newborn is sensitive to periodicities induced by a varying rhythm. Although learning by movement is probably important, the newborn auditory system is apparently sensitive to periodicities and develops expectations about when a new cycle should start. This result is fully compatible with the notion that BI is innate. However, it is still an open question whether this regularity detection in newborns is restricted to beat only, or whether it can be hierarchical, either as a (statistically) learned structural property of the stimulus or by inducing multiple levels of periodicity. Finally, with regard to the domain specificity and species specificity of BI, convincing evidence is still lacking and both of these aspects are the topics of current research.

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Conflicts of interest

The author declares no conflicts of interest.

References

1. Honing, H. & A. Ploeger. Cognition and the evolution of music: pitfalls and prospects. *Topics Cogn. Sci*. In press.
2. Povel, D.J. & P. Essens. 1985. Perception of temporal patterns. *Music Percept.* **2:** 411–440.
3. Desain, P. & H. Honing. 1999. Computational models of beat induction: the rule-based approach. *J. New Music Res.* **28:** 29–42.
4. Large, E.W. & M.R. Jones. 1999. The dynamics of attending: how people track time-varying events. *Psychol. Rev.* **10:** 119–159.
5. McAuley, J.D., M.R. Jones, S. Holub, *et al*. 2006. The time of our lives: life span development of timing and event tracking. *J. Exp. Psychol. Gen.* **135:** 348–367.
6. Hannon, E.E. & S.E. Trehub. 2005. Metrical categories in infancy and adulthood. *Psychol. Sci.* **16:** 48–55.
7. Fitch, W.T. 2006. The biology and evolution of music: a comparative perspective. *Cognition* **100:** 173.
8. Grahn, J.A. & M. Brett. 2007. Rhythm and beat perception in motor areas of the brain. *J. Cogn. Neurosci.* **19:** 893–906.
9. Grube, M., F.E. Cooper, P.F. Chinnery & T.D. Griffiths. 2010. Dissociation of duration-based and beat-based auditory timing in cerebellar degeneration. *Proc. Natl. Acad. Sci. USA* **107:** 11597–11601.
10. Trehub, S.E. & E.E. Hannon. 2006. Infant music perception: domain-general or domain-specific mechanisms? *Cognition* **100:** 73–99.
11. Phillips-Silver, J. & L.J. Trainor. 2005. Feeling the beat: movement influences infants' rhythm perception. *Science* **308:** 1430.
12. Zentner, M. & T. Eerola. 2010. Rhythmic engagement with music in infancy. *Proc. Natl. Acad. Sci. USA* **107:** 5768–5773.
13. Winkler, I., G. Haden, O. Ladinig, *et al*. 2009. Newborn infants detect the beat in music. *Proc. Natl. Acad. Sci. USA* **106:** 2468–2471.
14. Honing, H., O. Ladinig, I. Winkler & G. Háden. 2009. Is beat induction innate or learned? Probing emergent meter perception in adults and newborns using event-related brain potentials (ERP). *Ann. N.Y. Acad. Sci.* **1169:** 93–96.
15. Hannon, E.E. & S.P. Johnson. 2005. Infants use meter to categorize rhythms and melodies: implications for musical structure learning. *Cogn. Psychol.* **50:** 354–377.
16. Ladinig, O., H. Honing, G. Háden & I. Winkler. 2009. Probing attentive and pre-attentive emergent meter in adult listeners with no extensive music training. *Music Percept.* **26:** 377–386.
17. Winkler, I., E. Kushnerenko, J. Horváth, *et al*. 2003. Newborn infants can organize the auditory world. *Proc. Natl. Acad. Sci. USA* **100:** 1182–1185.
18. Honing, H. Structure and interpretation of rhythm and timing in music. In *Psychology of Music*. 3rd ed. D. Deutsch, Ed. Academic Press. London. In press.
19. Longuet-Higgins, H.C. & C.S. Lee. 1984. The rhythmic interpretation of monophonic music. *Music Percept.* **1:** 424–441.
20. Oxford Music Online. 2011. Entry 'Syncopation'. Available at: http://www.oxfordmusiconline.com/subscriber/article/grove/music/27263.
21. Brochard, R., D. Abecasis, D. Potter, *et al*. 2003. The "tick-tock" of our internal clock: direct brain evidence of subjective accents in isochronous sequences. *Psychol. Sci.* **14:** 362–366.
22. Drake, C. & D. Bertrand. 2001. The quest for universals in temporal processing in music. *Ann. N.Y. Acad. Sci.* **930:** 17–27.
23. Fitch, W.T. & A.J. Rosenfeld. 2007. Perception and production of syncopated rhythms. *Music Percept.* **25:** 43–58.
24. Honing, H. 2011. *The Illiterate Listener*. *On Music Cognition, Musicality and Methodology*. Amsterdam University Press. Amsterdam.
25. Winkler, I. 2007. Interpreting the mismatch negativity (MMN). *J. Psychophysiol.* **21:** 147–163.
26. Paavilainen, P., P. Arajärvi & R. Takegata. 2007. Preattentive detection of nonsalient contingencies between auditory features. *Neuroreport* **18:** 159–163.
27. Bendixen, A., E. Schröger & I. Winkler. 2009. I heard that coming: event-related potential evidence for stimulus-driven prediction in the auditory system. *J. Neurosci.* **29:** 8447–8451.
28. Schröger, E. & I. Winkler. 1995. Presentation rate and magnitude of stimulus deviance effects on human pre-attentive change detection. *Neurosci. Lett.* **193:** 185–188.
29. Näätänen, R., T. Kujala & I. Winkler. 2010. Auditory processing that leads to conscious perception: a unique window to central auditory processing opened by the mismatch negativity and related responses. *Psychophysiology* **48:** 4–22.
30. Gaab, D. (this volume). Current fMRI methods with children. *Ann. N.Y. Acad. Sci.*
31. May, P.J.C. & H. Tiitinen. 2010. Mismatch negativity (MMN), the deviance-elicited auditory deflection, explained. *Psychophysiology* **47:** 66–122.
32. Yabe, H., M. Tervaniemi, K. Reinikainen & R. Näätänen. 1997. Temporal window of integration revealed by MMN to sound omission. *NeuroReport* **8:** 1971–1974.

33. Ladinig, O., H. Honing, G. Háden & I. Winkler. 2011. Erratum to probing attentive and pre-attentive emergent meter in adult listeners with no extensive music training. *Music Percept.* **26:** 444.
34. Honing, H. & F. Bouwer. 2011. Is hierarchy in rhythm perception consciously learned? In *Proceedings of the Rhythm Perception and Production Workshop*. Max Planck Institute for Human Cognitive and Brain Sciences. Leipzig.
35. Patel, A.D. 2008. *Music, Language, and the Brain.* Oxford University Press. Oxford.
36. Fitch, W.T. 2009. Biology of music: another one bites the dust. *Curr. Biol.* **19:** 403–404.
37. Patel, A.D., J.R. Iversen, M.R. Bregman & I. Schulz. 2009. Studying synchronization to a musical beat in nonhuman animals. *Ann. N.Y. Acad. Sci.* **1169:** 459–469.
38. Zarco, W., H. Merchant, L. Prado & J.C. Mendez. 2009. Subsecond timing in primates: comparison of interval production between human subjects and rhesus monkeys. *J. Neurophysiol.* **102:** 3191–3202.
39. De Waal, F.B.M. 2009. Darwin's last laugh. *Nature* **460:** 175.
40. Nelken, I. & N. Ulanovsky. 2007. Mismatch negativity and stimulus-specific adaptation in animal models. *J. Psychophysiol.* **21:** 214–223.