HENKJAN HONING

The Illiterate Listener

On Music Cognition, Musicality and Methodology

Vossiuspers UvA

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In memory of H. Christopher Longuet-Higgins (1923-2004)

French babies cry differently than German babies. That was the conclusion of a study published at the end of 2009 in the scientific journal *Current Biology*.[1] German babies were found to cry with a descending pitch; French babies, on the other hand, with an ascending pitch, descending slightly only at the end. It was a surprising observation, particularly in light of the currently accepted theory that when one cries, the pitch contour will always descend, as a physiological consequence of the rapidly decreasing pressure during the production of sound.[2] Apparently, babies only a few days old can influence not only the dynamics, but also the pitch contour of their crying. Why would they do this?

The researchers interpreted it as the first steps in the development of language: in spoken French, the average intonation contour is ascending,[3] while in German it is just the opposite.[4] This, combined with the fact that human hearing is already functional during the last trimester of pregnancy, led the researchers to conclude that these babies absorbed the intonation patterns of the spoken language in their environment in the last months of pregnancy and consequently imitated it when they cried.

This observation was also surprising because until now one generally assumed that infants only develop an awareness for their mother tongue between six and eighteen months, and imitate it in their babbling.[5] Could this indeed be unique evidence, as the researchers emphasized, that language sensitivity is already present at a very early stage? Or are other interpretations possible?

Although the facts are clear, this interpretation is a typical example of what one could call a language bias: the linguist's understandable enthusiasm to interpret many of nature's phenomena as linguistic. There is, however, much more to be said for the notion that these newborn babies exhibit an aptitude whose origins are found not in language but in music.

We have known for some time that babies possess a keen perceptual sensitivity for the melodic, rhythmic and dynamic aspects of speech and music:[6] aspects that linguists are inclined to categorize under the term 'prosody', but which are in fact the building blocks of music.[7] Only much later in a child's development does he make use of this 'musical prosody', for instance in delineating and subsequently recognizing word boundaries.[8] But let me emphasize that these very early indications of musical aptitude are not in essence linguistic.

The message should be clear by now: I am referring here to 'illiterate listening', the human ability to discern, interpret and appreciate musical nuances already from day one, long before a single word has been uttered, let alone conceived. It is the preverbal and preliterate stage that is dominated by musical listening.

There is still much to be discovered about this apparently innate aptitude for music, which I'll call 'musicality'. It is one of the core topics of the research I hope to develop with the help of this endowed chair in music cognition. I shall return to it here in due course, together with a number of comments on methodology. But first let me return to the friction between linguistic and musical research, and its place in the field of music cognition.

Music and language

Music and language are usually compared to one another on the point of syntax: the division of music into notes and phrases, and of language into words and sentences. It presupposes an analogy between language and music that has inspired many a music researcher to apply linguistic methods to music analysis.[9]

One well-known example is *A Generative Theory of Tonal Music*, published in 1983 by the musicologist Fred Lerdahl and the linguist Ray Jackendoff.[10] In their book, the authors set out to explicitly define the music-theoretical knowledge a listener implicitly uses when listening to music. They devised a (semi-) formal theory that describes the musical intuitions of a listener who possesses significant experience with the Western classical idiom.[11] In that sense it was one of the first cognitive theories about music.

The accompanying diagram (Fig. 1) shows, with the help of Lerdahl and Jackendoff's theory, a structural analysis of a familiar melody. The melodic relationships between the notes are rendered in a reverse 'tree structure', with the 'leaves' of the tree – the notes – at the bottom. In such structural analyses, the elements have a hierarchical relationship: some elements – in this case certain notes – are secondary to others.

The last note (a C) is, for example, secondary to the first note (also a C) because it hangs on a lateral branch. The third note (G) is the lowest in the hierarchy and therefore the least important. In short, the fewer the number of branches between a 'leaf' (a note) and the 'trunk' (at the top of the diagram), the greater the importance the analysis affords that note.

Syntactical tree structures like these are derived from Chomsky's theories on language, where they are used to visualize the grammatical structure of sentences,[12] as shown in the illustration below (Fig. 2).

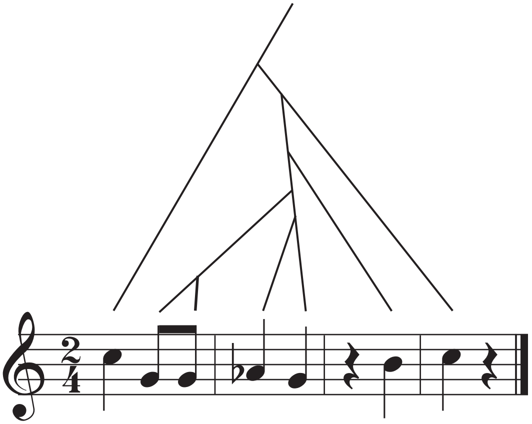

Fig. 1 Structural analysis of a familiar melody

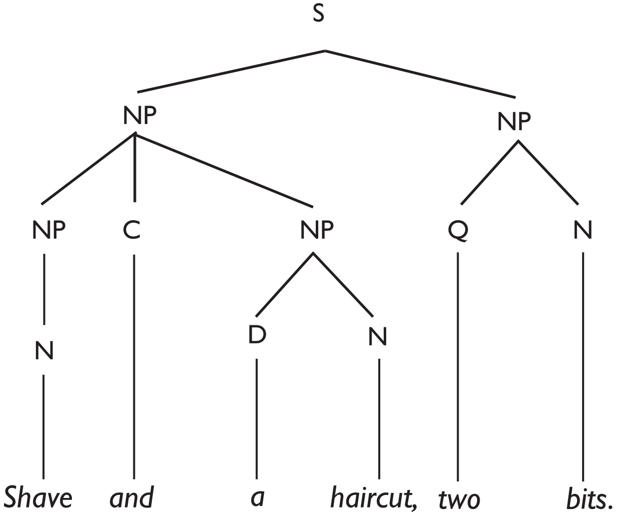

Fig. 2 Example of a linguistic tree

In a linguistic tree, the branches are labelled according to the function of the words that fall under each particular branch. The grammar generated by this kind of system determines which branches are possible (syntactically correct) and which are not.

Music has considerably fewer grammatical restrictions than language; notes and phrases can be used in any number of combinations and sequences. This is not to say that structure plays no role at all in music, but as it lacks semantics, a melody cannot be said to be syntactically 'wrong'. A sentence like 'the listener illiterate is' is perfectly possible in music, but not in spoken or written language, whose point, of course, is communication. In this sense music is more akin to poetry, where the laws of syntax likewise play a lesser role.

The parallels between language and music, however, still make it tempting to seek out structural similarities between these phenomena. Even in more recent studies offering alternatives for the Chomskyan research programme – such as *Data-Oriented Parsing* by Remko Scha and colleagues at this university[13] – the researchers employ the central concept of tree structures, making it possible to theorize in a similar way about language and music.

At first, Lerdahl and Jackendoff's theory drew criticism as well as praise. One criticism was that much was left to the reader's interpretation; for example, the way in which formal preference rules should be combined to attain a factual analysis. This might seem attractive to analysts, but for psychologists and computer scientists who desire to test or apply the theory, it lacked a formalization of this essential last step.[14]

The second point of criticism was that all analyses are based on information present in the score. But to what extent is a score a perceptual reality, that is, a reflection of what the listener hears? Lerdahl and Jackendoff's music theory, and subsequently related theories,[15] abstract from the actual music in their notations, just as the linguist, in analyzing written texts, abstracts from spoken language. Lerdahl and Jackendoff in fact presented a semi-formal model of 'the literate listener'.

Even today, letters or symbols arranged in tree structures are still a central element of both the Chomskyan research programme and the relatively recent probabilistic approach to language and music. They are often presented as opposites, though: while the Chomskyan theory presumes an innate generative grammar, data-oriented theories emphasize the role of learning. Both nonetheless assume that the object of their research – language or music – can be reduced to a collection of symbols. Just as a text is made up of letters, a score is made up of notes.

This assumption has the great advantage that it allows the syntax of language and of music to be described and understood in the same way. The work of Lerdahl and Jackendoff is an excellent example of this. The question remains, though, of whether this assumption is entirely accurate. While in practice it is definitely possible to represent both music and language in symbols, in the case of music cognition it is doubtful whether these symbols (i.e., notes) are meaningful basic units that can be arranged in a tree structure. What do a musical score and a tree structure say about the listening experience? It may well be that the trees of modern linguistics obscure the forest of music.

'Ooh-ooh-ooh,' sang Billie Holiday in 1957 at the Newport Jazz festival: an opening riff followed by the playfully rhyming 'what a little moonlight can do-oo-oo'. Words and sounds that instantly brighten your spirits. The transcription of this opening text reveals a straightforward string of three consecutive 'ooh's'. But it is virtually impossible to reduce them meaningfully to individual notes. Where does one note end and the next one begin? It is a fairly futile exercise: the meaning of 'ooh-ooh-ooh' is not to be found in a combination of the individual sounds but in the indivisible whole.

This example demonstrates that in this case, letters – and language in general – fall short. The linguist Ray Jackendoff, and others with him, dismiss melodic utterances like 'ooh', 'ow', 'wow' or 'hey' as relics from the single-word stage of language.[16] Others, however, are in my opinion correct in emphasizing that such expressions represent a fundamental and primeval aspect of language. Perhaps it is even a sign that music predates language. 'Ooh-ooh-ooh' is a good example of what the cognitive archaeologist Steven Mithen means by 'proto-language': a kind of 'sung language' that preceded our music and our modern language. It is a vision he unfolds with great flair in his book *The Singing Neanderthals*[17] and that he presented for discussion at a symposium at the University of Amsterdam in 2005.[18]

But Mithen too, it appears, is not entirely immune to language bias. 'Proto-language' could just as easily be called 'proto-music': not individual words in search of a grammar (as Jackendoff suggests) but inseparable utterances of musical-human emotion. The significance is carried in subtle nuances in pitch, rhythm and dynamics – nuances to which newborn babies are apparently highly sensitive, as shown in the research mentioned at the beginning of this article. But adults too have little difficulty in judging whether a sentence is intended as a question, a statement or an ironic comment.

These melodic forms of expression could well touch on the essence of music, whereby the rest – particularly the above-mentioned tree structure – is reduced to 'syntactic sugar': an added, educated view of listening that seems to obscure the essence of music.

But what's the answer then? Can the mystery of music be uncovered? This is a question that has plagued many a music philosopher. And the answer is usually, after much meandering, a simple 'no'.[19] I am convinced, however, that music, scientifically speaking, does not necessarily have to pose any greater mystery than other human activities such as chess, sports, lovemaking or politics – activities, it has been shown, that are open to scientific study. The tool chest of the cognitive sciences in particular is well-equipped to chart the various aspects of music and listening. Before discussing the toolbox, the methodology, let us take a look at this relatively recent field itself.

Music cognition

One of the pioneers in the field that would come to be called music cognition was H. Christopher Longuet-Higgins (1923-2004).[20] Not only was Longuet-Higgins one of the founders of *cognitive sciences* (he coined the term himself in 1973),[21] but as early as 1976 he published his first computer model of musical perception in the journal *Nature*,[22] seven years earlier than the more widely known, but less precisely formulated, book by Lerdahl and Jackendoff. It was a thorn in Longuet-Higgins's side. In a review in that same journal, he wrote:

> 'Lerdahl and Jackendoff are, it seems, in favour of constructing a formally precise theory of music, in principle but not in practice.'[23]

Although Lerdahl and Jackendorff's book was far more precise than any musicological discussion found in the leading encyclopedias, to my mind Longuet-Higgins is justified in criticizing their often unnecessary lack of precision.

The importance of formalizing this wealth of knowledge cannot be underestimated,[24] if only because exactifying knowledge is an effective way to open up a discipline and subsequently make it accessible and applicable to other disciplines. Notwithstanding all our musicological knowledge, many fundamental concepts are in fact treated as axioms; musicologists are, after all, anxious to tackle far more interesting matters than basic notions like tempo or metre. But these axioms are not in actual fact understood, in the sense that we are not able to formalize them sufficiently to explain them to a computer. This is still the challenge of 'computer modelling' (and of recent initiatives such as *computational humanities*)[25] – a challenge that Longuet-Higgins was one of the first to take up.[26]

One example of this type of basic musicological concept is the *syncope*. Most music encyclopedias describe a syncope (or syncopation) as 'an accent that has been moved forward', and 'to syncopate' as 'a technique often used by composers to avoid regularity in rhythm by displacing an emphasis in that rhythm'.[27] Lerdahl and Jackendorff define it as follows:

> 'In general the phenomenon of syncopation can be formally [*sic*] characterized as a situation [*sic*] in which the global demands of metrical well-formedness conflict with and override local preferences.'[28]

I reprint it here as Longuet-Higgins quoted it in his book review.[29] With two minor additions (in brackets) he exposes the weakness of this passage: it lacks a formal definition of the concept of 'syncopation', and the conditions under which it occurs are left vague.

Not leaving it at that, the following year (1984) Longuet-Higgins published a remarkably straightforward definition that has been used until the present day.[30] I shall illustrate it presently, with the aid of an example. But let me begin with a question. Which of the two rhythms below do you believe is syncopated?

Fig. 3 Which rhythm is syncopated?

Anyone who can read musical notation – the 'literate listener' – will quite effortlessly choose the example on the left, guided by the slur that indicates a syncope, literally a 'joined beat'. However, if one were to ask a percussionist to play precisely what is notated,[31] both rhythms will sound identical. The literate listener is misled by the letters, or in this case the notation. And by 'literate' listener I mean not only the reading listener but all musicological disciplines that take the 'data' – the letters and symbols – too seriously[32] in the sense that one often mistakenly believes that all the information is contained in the 'data', in this case the notation.

The illiterate listener hears the same thing, but his expectation is different. What he expects is not based on the score, but depends on what he or she has heard before.[33] Usually that is comparable to the left-hand example, because we Western listeners tend to hear in unfamiliar music the more commonplace duple (two-part) division. If, however, the listener expects a compound metre, as in the right-hand example, then the syncopation vanishes entirely.

The following diagram (Fig. 4) illustrates why Longuet-Higgins's theory predicts that this rhythm will feel like a syncopation when notated in 2/4 time, while the identical rhythm notated in 6/8 time will not.

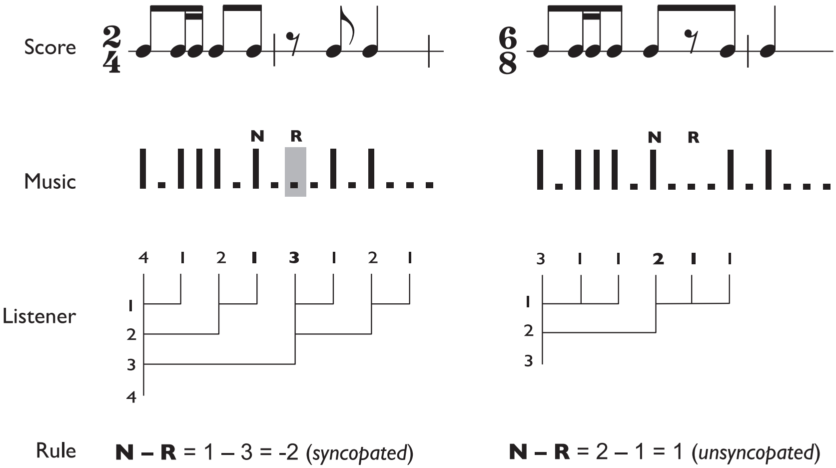

Fig. 4 Two possible notations (marked as 'Score') of an identical rhythm (marked as 'Music'). At left (marked as 'Listener'), the rhythm is interpreted as accommodated in a simple duple metre; at right, as a compound metre. The model then predicts (marked as 'Rule') that the left-hand rhythm is syncopated and the right-hand one not. The numbers underneath the printed rhythm, given in stripes (notes) and dots (rests), indicate the metrical emphasis, i.e. the depth of the metrical tree at the particular position. A negative difference between a note (N) and a rest (R) indicates the strength of the syncopation; a positive sum indicates the absence of syncopation.

In addition to quantifying the concept of syncopation with a simple calculation, the most important insight here is that the syncopatedness of a rhythmic passage is defined as an *interaction* between the music (the rhythm one hears) and the listener (who projects a metre onto it). This insight lies at the basis of music cognition research and says, in fact: *no listener, no music.*

In this case, the listener's expectation creates a 'loud rest': a crashing 'nothing' at the moment he expects to hear a note (see the rest, highlighted in grey, in the left-hand example).[34] That expectation is the product of not only our experience (exposure to music) but, as I will presently show, partly of our own biology as well.

Where does that feeling for regularity, or metrical sensitivity, come from? In Longuet-Higgins's model, the metre (or time signature) was a given, an aspect that did not figure into the theory and which had to be provided by the user. Since then, much research has been done into what is called *beat induction* and *metre induction*, which addresses the question of how listeners hear regularity in music, and why some rests pass by unnoticed while others confront the listener as 'loud nothing'. The fact that the one rest is intrusive and another, physically identical rest is not, is a suitable index to measure whether a person has a certain metrical expectation. We turn Longuet-Higgins's model back-to-front, as it were.

With this idea as a starting point, three years ago I began working, together with István Winkler from the Hungarian Academy of Sciences, on an empirical way to measure this theory. We applied a method that measures brain activity during listening, and with which one can determine whether a certain event (or the absence of that event) is expected or not.[35]

The experiments we conducted with Hungarian students as participants – listeners without explicit musical training – clearly showed that the brain of an illiterate listener possesses a strong feeling for metre: the subjects were (unconsciously) taken by surprise by a 'loud' rest, but not by a 'quiet' one. Even in a situation in which the subjects were asked to focus their attention elsewhere, such as subtitles of a self-chosen muted video film, the brain consistently made this distinction.[36] The brain induced the beat (hence the term 'beat induction'): the absence of a note at the spot where a beat was expected sent the brain a 'surprise signal', the *mismatch negativity* (MMN).[37]

We then wanted to know to what extent beat induction is innate or can be learned. There is much to be said for the notion that beat induction is a fundamental cognitive and music-specific skill. It makes us capable of dancing together or playing music together: *no beat induction, no music.*

In order to investigate this, we conducted a new experiment with a group of ultimate 'illiterate listeners': two- to three-day-old babies.[38] To our surprise, the brains of these babies reacted similarly to those of the adults. Shortly after the expected 'loud rest' the babies' brain signal exhibited a peak, a sign that the brain had expected a note at that spot. Even newborn babies appeared to possess a very clear sensitivity for metre.[39]

Musicality

This result of empirical research placed our earlier studies of beat induction – which were hitherto mainly musicological and computational in nature – in an entirely new perspective. Why were these babies consistently surprised by the omission of a beat in a varying rhythm? Were we observing an innate aptitude, or at least a biological function active from day one?[40] Is beat induction a music-specific, or even a human-specific trait? And could beat induction have played a role in the evolution of music?

Until recently, researchers have believed that beat induction is learned, for example by being rocked by one's parents to the beat of the music. But our study showed this to be improbable; it undoubtedly has an effect on the further development of metrical sensitivity, but the basic skill is clearly present immediately after birth.

It is therefore remarkable that while most humans have little trouble tapping their foot to the beat of the music, or to hear whether music speeds up or slows down, it is still impossible to get species closely related to us (such as chimpanzees or bonobos) to clap or drum to the beat of the music.[41] They appear not to have a feeling for metre. Certain species of bird, however – parrots and cockatoos, for instance – do seem to be able to hear a beat, as recent studies by North American researchers claim.[42] Should this indeed be the case, then it makes the phenomenon even more intriguing, and the evolutionary implications more open for research.[43] What traits do we share with these bird species (and not with other primates), and what can this teach us about the evolution of music?

The theme of 'Music and evolution' has significantly determined the agenda of international conferences and the relevant journals in the past year. Despite the fact that the scientific study of the evolution of cognition is regarded by some as well-nigh impossible, doomed to remain, at best, an engaging story,[44] various researchers are developing strategies to empirically support the cognitive and biological role of musicality. Together with Annemie Ploeger (evolutionary psychologist at the University of Amsterdam) I have recently begun developing one such possible strategy. Its aim is to hone in on and precisely define the fundamental mechanisms from which musicality appears to be built, and subsequently to support this with empirical evidence drawn from various sources and disciplines.[45] But we are not the only ones engaged in this kind of research programme. Colleagues Ani Patel from the Neuroscience Institute in San Diego[46] and Tecumseh Fitch, presently affiliated with the University of Vienna,[47] are also very interested in mapping out the evolutionary role of music.

Methodology

I hope the preceding sections have given an impression of a few of the issues occupying myself and the field of music cognition, but also, indirectly, of the methods used in addressing those issues. I emphasized the role of formalization, the importance of empiricism and the function of computational modelling, in which the two converge. I would like, in closing, to take a more in-depth look at this last method.

Computational modelling was no more than a promising idea in the days when Longuet-Higgins published his first computer model in *Nature*. Since then it has grown into a prominent methodology in the cognitive sciences. At present, there is hardly a cognitive theory without a computational component. At the same time, this methodology threatens to become a victim of its own success, certainly if one looks at the enormous number of alternative models available for comparable phenomena (such as beat induction).

One might claim that the humanities, with recent initiatives such as *computational humanities*, in that sense lag behind, with the danger of becoming stuck at a place that the rest of the scientific world has long since left in its wake. I consider that, however, an incorrect assessment.

As in every scientific discipline, it is important to strike a balance between empiricism and theory. And the method of computational modelling could perhaps have more potency than stating a vision, developing an interpretive framework or the simple testing of hypotheses (all of which are not uncommon in the humanities and social sciences). Computational modelling is a powerful method that unites both aspects – theory and empiricism – and whose central idea is a methodological cycle in which a theory is made so precise that it can be formalized and expressed in an algorithm. The validity and breadth of the theory (now in the form of a computational model) can then be tested in experiments and with simulations, and – should the predictions not be entirely in agreement with the empirical facts – subsequently the algorithm can be adapted and consequently the theory.[48] By including more and more related aspects of a specific phenomenon (in the form of empirically tested hypotheses) in the model, one hopes that the model will become an insightful and understandable illustration of a specific process, its properties and the relationships between them.

A computational model also has intrinsic properties. The availability of a model, for instance, allows us to make precise theoretical predictions independent of the data, the empirical observations. A model can, in principle, express things about related problems for which it was not designed. These predictions, which are a consequence of the collection of properties, each of which has an empirical basis but has not yet been tested per se, are to a great extent the advantage of a model in computational form. As such, a model can be used to generate new hypotheses.

But of course not all predictions are equally interesting. A model that makes a surprising prediction is, in that sense, preferable above a model that predicts something we already expected. Karl Popper expresses this idea nicely in his *Conjectures and Refutations*:

> 'Confirmations [of a theory] should count only if they are the result of risky predictions; that is to say, if, unenlightened by the theory in question, we should have expected an event which was incompatible with the theory – an event which would have refuted the theory.'[49]

Although Popper is principally known for emphasizing the scientific importance of falsification, this is a fine example of his thinking about exactly the opposite: confirmation. The quote expresses the intuitive idea that I hope to expand in the coming years, together with Jan-Willem Romeijn (philosopher of science at the University of Groningen), to a quantitative *measure of surprise* that can serve as an alternative to better-known criteria for model selection, such as *goodness of fit* – prefer the model that best predicts the data – and *simplicity* – prefer the simplest model – much-used criteria in the cognitive sciences.[50]

The central question in this study is: how surprising are the predictions that can be made by a specific computational model, regardless of the possible empirical observations? The second question is then: what role can the making of risky predictions play in preferring one model over the other? This makes it possible to reduce the enormous number of alternative models, for example in the area of beat induction, to a realistic number, and – more interestingly – to give more direction to the current plethora of hypothesis tests.[51]

These are ideas, incidentally, that do not appear to be particularly closely related to humanistic thinking. But I still feel that notions such as 'risky prediction' or 'surprising consequence' can also play an important role in the humanities. With a measure of surprise, for example, other humanistic theories (think of the historical sciences or archaeology) can be compared and evaluated with partial or no evidence. Admittedly, these are for the most part hypothetical promises, but we have now at least made a start.[52]

Epilogue

Music. For most people it is an art. A unique talent that has led to remarkable works of art, compositions that can be interpreted and analyzed over and over again. But if music is art, why (and how) would you want to study it scientifically?

The neuroscientist Robert Zatorre (University of Montréal) used, until recently, the term '*complex non-linguistic auditory processing*' instead of 'music' in his research applications, because he knew that the application would otherwise be brushed aside as unscientific.[53] Fortunately, music researchers' self-image is changing, particularly through the idea that music is intimately linked with who we are, what we do, feel and know, and through the cognitive and neurosciences' growing interest in the phenomenon of music as a unique human trait.[54] Hence my emphasis in this essay on the unique characteristic of music, namely that it speaks directly to us without the intervention of letters or grammar. The crying babies at the beginning of this essay and the listening babies with a feeling for beat are two clear examples of this. In that sense, a newborn baby embodies the ultimate listener, an illiterate listener that resides in all of us.

In closing I shall summarize the main points of the proposed study. It is divided into three areas that I hope to develop further in the next few years.

First, study of the cognitive mechanisms that lie at the basis of musicality. It is one of the subjects in the research project to be initiated shortly within the research priority programme entitled *Brain & Cognition* at this university, a project that aims to further chart the role of attention and consciousness in rhythm perception.[55] Additionally, these cognitive mechanisms – when they are charted precisely – lend themselves to empirical support of a possible adaptive role of musicality. In regard to this last aspect, collaboration with biologists and evolutionary psychologists has a high priority.

Second, the further development and evaluation of the recently developed methodology of computational modelling, and in particular the extent to which surprise plays a role in this kind of model. This research theme has the potential to build bridges to other humanistic disciplines, especially in the framework of the *computational humanities*. I hope to engage in an inspiring co-operative effort with other science philosophers and computational linguists.

And third, the further exploration of the role of the Internet in studying the process of listening to music. I have not elaborated on it here, but in addition to the extensive and accessible listening experiments we conducted earlier,[56] social networks and other Internet-related developments offer a rich source of listening research and therein the role of music cognition.[57] It is our aim to initiate this project as well in the near future, together with colleagues at this and other universities.

⁂

Acknowledgements

I would like to express my thanks to the Academy Chairs in the Humanities Foundation of the Royal Netherlands Academy of Arts and Sciences (KNAW), which nominated me for the privilege of being named to this distinguished professorship, with the teaching subject of music cognition. I likewise extend these thanks to the Faculty of Humanities and the Executive Board of the University of Amsterdam, for the confidence which they have entrusted in me.

I can certainly thank some of this confidence to John A. Michon, but also to Frank Veltman, Johan van Benthem, Frans Grijzenhout, Hotze Mulder, Koen Hilberdink and José van Dijck, and the members of the curatorial committee of this professorship: Guillaume van Gemert, Rokus de Groot and Martin Stokhof. To them I extend my heartfelt gratitude.

I shall keep the rest of these acknowledgements brief. I will refrain from thanking my colleagues, students and ex-students, my parents, brothers, good friends and even my partner, simply because here too, letters do not suffice.

Notes

1. Mampe et al. (2009).
2. Lieberman (1985).
3. Welby (2006).
4. Wiese (1996).
5. Hallé, de Boysson-Bardies & Vihman (1991).
6. Trehub (2003).
7. Honing (2011a), pp. 3-13.
8. Mattys, Jusczyk, Luce & Morgan (1999).
9. This paragraph is a reworking of 'Music as language' from Honing (2011a).
10. Lerdahl & Jackendoff (1983).
11. Lerdahl & Jackendoff (1983), p. 1.
12. Chomsky (1957).
13. Bod, Scha, & Sima'an (2003).
14. See Lerdahl (2009).
15. For instance, Heinrich Schenker or Eugene Narmour.
16. Jackendoff (2002).
17. Mithen (2005).
18. See http://www.hum.uva.nl/mmm/origins/.
19. See, for example, Raffman (1993).
20. Longuet-Higgins had a remarkable academic career. He began as a 29-year-old professor of theoretical physics at King's College in London and was appointed professor of theoretical chemistry at Cambridge two years later. Additionally, he studied music at Oxford and was active as a composer, conductor and pianist. At about the age of 40 he took the rigorous step of moving to the new field of artificial intelligence and became the Royal Society Research Professor at the University of Edinburgh, eventually moving to the Department of Experimental Psychology at the University of Sussex in 1974, where he remained until his retirement. He wrote groundbreaking articles on a variety of topics, including computer vision, computer linguistics, memory and musical cognition (collected in Longuet-Higgins, 1987).
21. Longuet-Higgins wrote: 'Perhaps "cognitive science" in the singular would be preferable to the plural form, in view of the ultimate impossibility of viewing any of these subjects [i.e. mathematics, linguistics, psychology and physiology] in isolation.' (Longuet-Higgins, 1973; Reprinted in Longuet-Higgins, 1987).
22. Longuet-Higgins (1976).
23. Longuet-Higgins (1983).
24. Honing (2009), p. 47-50.
25. Willekens et al. (2010).
26. Longuet-Higgins (1987).
27. Grove Music Online (2011). Under 'Syncopation'. See http://www.oxfordmusiconline.com/subscriber/article/grove/music/27263.
28. Lerdahl & Jackendoff (1983), p. 77.
29. Longuet-Higgins (1983), p. 93.

30. Longuet-Higgins & Lee (1984).
31. which, incidentally, rarely happens; see Honing (2011a), p. 104.
32. Honing (2011b).
33. Huron (2008).
34. A notation with a rest is thus more appropriate than one with a slur.
35. We did this with the help of an electroencephalogram (EEG). An EEG, however, measures a good deal of neural activity unrelated to the reaction to the sound or the music. Therefore, we looked for *event-related potentials* (ERP), small fragments of signal from the EEG that occur at a set time following a sound (an *event*), and with the help of a computer can be added up and averaged. The 'white noise' is reduced, and the resulting signal is 'cleaner'.
36. Ladinig, Honing, Háden & Winkler (2009).
37. The phenomenon known as *mismatch negativity* (MMN), discovered in 1978 by Riso Näätänen, is seen as the unconscious orientation of the brain to deviating sound stimuli. It has proved to be a reliable measure, indicating whether a particular sound aspect such as pitch, duration or intensity is experienced as 'out of place'. The MMN can therefore be used to test the extent to which the expectations of a listener are breached.
38. Honing, Ladinig, Winkler & Háden (2009).
39. Winkler, Háden, Ladinig, Sziller & Honing (2009).
40. Babies' sense of hearing is already functional three months before birth. When the brain is in the process of development, it is difficult to indicate whether we are observing an innate trait that is 'switched on' at a certain point, or a trait that has been learned.
41. Zarco, Merchant, Prado & Mendez (2009).
42. Fitch (2009).
43. De Waal & Ferrari (2010).
44. Lewontin (1998).
45. Honing & Ploeger (2011, still to be published).
46. Patel (2010).
47. Fitch (2006).
48. Desain & Honing (2004).
49. Popper (1963).
50. Pitt & Myung (2002).
51. Honing (2006a).
52. Honing (2006b) and Honing & Romeijn (submitted).
53. Robert Zatorre, quoted by Ani Patel in the *New York Times* of June 1, 2010. Also at http://www.nytimes.com/2010/06/01/science/01conv.html.
54. Zatorre (2005).
55. http://www.mindopen.nl/MindOpen_nr5.html.
56. Honing & Ladinig (2009).
57. Honing (2011b) and Honing & Reips (2008).

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