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PROBING PERCEPTUAL CAPABILITIES UNDERLYING MUSIC PERCEPTION

PhD thesis booklet

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Budapest, 2011

General background and aim of the thesis

The general aim of this thesis is to shed light on the question: Which of the abilities underlying the perception of music are functional at the time of birth. Music perception is obviously a higher cognitive function, which depends on several abilities. However, the exact nature of these dependences is far from being trivial. Music perception, similarly to other higher functions of cognition, can be seen as the product of complex interactions between innate predispositions and constraints on information processing, the physical and cultural constraints determining what information is available in the environment, and the process of learning through which quantitative and qualitative differences in information processing emerge as a function of experience over time. Notwithstanding the complex nature of music, it is possible to identify general processes of auditory perception which serve as the building blocks necessary for music perception. Both the functional architecture and the ontogenesis of these abilities provide crucial cues for understanding the role learning plays in music. By applying electrophysiological methods, sources of information inaccessible to traditional behavioral methods can be tapped. In adults, MMN paradigms allow access to processing steps with relatively low interference from attention and explicit knowledge of music. In newborn infants, similar paradigms can be used to study processing abilities functional at birth that would otherwise remain hidden behind the very limited repertoire of behavioral responses available to newborns.

Examining perception near the time of birth enables one to observe an “initial state” of the system (at least with respect to explicit learning), although one should not downplay the importance of intrauterine experiences. Knowledge of this “initial state” allows for better understanding of how music perception emerges by identifying the basic building bricks and comparisons between the different developmental stages. The innateness of specific abilities can be determined by examining infants shortly after birth. In theory, this approach could

provide supporting evidence for modular, domain-specific accounts of music processing. However, most of the perceptual abilities assessed in this thesis represent more basic processes, ones possibly shared by both music and other forms of communication by sounds.

Based on the principles above, the theses examine aspects of two equally important areas of music. Theses I and II are related to the perception of melody and theses III, IV and V are related to the perception of rhythm.

New scientific results

Thesis I: Relative pitch extraction in newborns (I.)

A sequence of rising and falling pitch steps can be interpreted as a melodic contour irrespective of the absolute pitch level and to some extent the sizes of pitch steps (Dowling, 1978; Edworthy, 1985). The ability to extract the relative sizes of pitch steps however is necessary to recognize melody in the context of both music and speech prosody. Adults are able to extract relative pitch information (Paavilainen et al., 1999; Tervaniemi et al., 2006) and it has been shown that newborns are sensitive to the direction of pitch intervals (Carral et al., 2005).

The ability of newborn infants to extract the size of pitch intervals irrespective of absolute pitch levels was tested. EEG was recorded while sequences of tone pairs with equal pitch steps were presented. The regular sequence was infrequently broken by tone pairs having a larger pitch step. All tone-pairs were presented at several randomly assigned absolute pitch levels. If newborn infants are able to extract the common size of pitch steps as an abstract regularity (in spite of variation in absolute pitch), then the infrequently presented large pitch steps should elicit an MMN-like ERP component in them. The presence of the MMN-like component would suggest that newborns are able to represent pitch intervals. MMN-like components were elicited by infrequent pitch steps, suggesting that newborns are able to process pitch interval information similarly to adults.

Thesis II: Timbre-independent extraction of pitch in newborns (II.)

Important spectral features other than pitch can be extracted from perceived sounds (e.g. McAdams et al., 1995; Handel, 2006). Adults are able to separate pitch from timbre information (Semal & Demany, 1991, 1993; Krumhansl & Iverson, 1992) and thus can identify different instruments playing the same note, or different speakers speaking the same

words. The independent extraction of pitch and timbre information is important in both music perception and language acquisition.

The aim of the study was to show that newborn infants can extract pitch information independently of timbre variations. An aspect of timbre, resonator size, was randomly varied over all sounds in a simple pitch oddball design. ERPs were recorded from newborn infants. If infrequent high pitch deviants presented among low pitch standards elicit an MMN-like response despite the random variation in resonator size, this result can be taken as evidence for timbre-independent processing of pitch in newborn infants. Results indicated that newborns represent pitch and resonator size information independently of each other.

Thesis III: Auditory temporal grouping in newborns (III.)

Sounds in an auditory scene can be grouped based on higher order regularities. These regularities can convey information for example on sound sources and can be used in representing the environment by constructing auditory objects (Bregman, 1990). Previous studies showed that newborn infants represent probabilities of local sound features, that is, they produce a discriminative response to infrequent deviant sounds presented among regular standards (for reviews, see e.g. Cheour, Leppänen & Kraus, 2000; He, Hotson & Trainor, 2007). Adults are also able to extract higher order regularities from sound sequences, such as the cyclical repetition of pitch patterns (Sussman, Ritter & Vaughan, 1998; Sussman et al., 2002; Sussman & Gumenyuk, 2005). This ability supports the construction of hierarchical sound representations, which is a necessary prerequisite for many complex functions, amongst them rhythm perception (Lerdahl & Jackendoff, 1983).

The objective of the present study was to investigate whether newborn infants form auditory groups from cyclically repeating pitch patterns. To this end, EEG was recorded while newborn infants were presenting with oddball sequences. The sequences were either random or they contained a cyclically repeating pitch pattern. The probability of the oddball sound

was uniformly fixed at 20% in both types of sequences. If only local probability is taken into account by the newborn auditory system for deviance detection, then oddballs in both types of sequences should elicit an MMN-like response. If grouping occurs, then the oddballs in the grouped sequence become part of the higher order regularity and should not elicit MMN. No MMN-like response was found for oddballs in the grouped sequence, which provided important, however indirect, evidence in support of the neonatal ability to group sounds based on cyclical repetition.

Thesis IV: Processing of meter in adults (IV.)

Rhythm perception can be structured by beat and meter (Lerdahl & Jackendoff, 1983). Beat induction, the ability to extract a regular beat or pulse from auditory stimuli and synchronize with that beat or pulse, underlies meter induction the ability to hierarchically order multiple regular beats. Metrical salience is assigned to specific positions in a rhythmic pattern based on the distance in the hierarchy from the downbeat (viz. the firs beat). Metrical salience shows the importance of a specific beat in defining a rhythm (Lerdahl & Jackendoff, 1983; London, 2002).

The goal of the study was to test with both behavioral and ERP measures whether adults automatically process metrical salience by constructing a rhythmic pattern and omitting beats at positions with different metrical salience. The patterns with beats omitted on significant positions were presented as oddballs in sequences consisting predominantly of patterns in which omissions occurred on less salient positions. Different levels of metrical salience were assumed to have an effect on both the sensitivity and reaction time (RT) measures in an omission-detection task. Differences in metrical salience could then also affect the latency of the MMN elicited by the omissions with no sound-related task as well as when the subjects performed a concurrent auditory task on a different sound stream. The results are not clear about the effect of attention on meter processing because in the concurrent task condition an

attention modulated N2b component may overlap the MMN. Sensitivity and ERP latency data supported the differentiation based on metrical salience, whereas support from RT measures and ERP amplitude data was weaker.

Thesis V: Beat detection in newborns (V.)

Beat induction, the ability to synchronize with a regular pulse or beat, plays a significant role in meter perception (Lerdahl & Jackendoff, 1983), but may also help coordinating communicative acts (Jaffe et al., 2001). Both infants and adults can form metric categories (Hannon & Trehub, 2005) and able to synchronize with a regular beat (Drake, 1993; Repp, 2005; Philips-Silver & Trainor, 2005). However it is not clear whether this ability is also present in newborns.

The experiments aimed at showing beat induction in newborn babies. A musically plausible rhythmic pattern was created and presented to sleeping newborns, with occasional omissions in the pattern at the positions with the highest (downbeat) and lowest metrical salience. If beat induction occurs in newborns, higher-amplitude MMN-like components should be elicited by omissions from the pattern at the most metrically salient as compared with the least salient positions. Responses were also compared with a physically identical control. Results of the experiments were in full accord with the notion of beat induction occurring in newborns. Results of a control experiment conducted in adults ruled out a possible alternative explanation of the neonate results. The alternative explanation was based on the assumption that the sounds of different instruments making up the test sound sequence were segregated to separate streams and sound omissions were separately detected for the different streams. However, no such omission responses were obtained in the adult participants.

Conclusions and further directions

Babies are born well-equipped for gathering information from the auditory environment. In many respects, their abilities are comparable to those of adults, if not in precision, certainly in function. The experiments of this thesis are amongst the first steps toward a systematic examination of neonatal auditory processing. Further experiments within the field of music perception should try to test broader theories about the origins and functional organization of music, as well as the underlying neuronal substrates. Abilities, which might be exclusive to music processing, should be one of the focal points of research. A good candidate for such an ability, which was identified in this thesis, is meter perception. The MMN-like response in newborns is a useful and proven tool for this endeavor, albeit one that itself is in need of further research. Finally, integrating music research with the study of language and the broader field of communication should yield a deeper understanding of human cognition.

List of publications related to theses

I. Stefanics, G., *Háden, G. P.*, Sziller, I., Balázs, L., Beke, A., Winkler, I. (2009) Newborn infants process pitch intervals. *Clinical Neurophysiology* 120. 304-308. DOI: 10.1016/j.clinph.2008.11.020

II. *Háden, G. P.*, Stefanics, G., Vestergaard, M. D., Denham, S. L., Sziller, I., Winkler, I. (2009) Timbre-independent extraction of pitch in newborn infants. *Psychophysiology* 46 (1), 69-74. DOI: 10.1111/j.1469-8986.2008.00749.x

III. Stefanics, G., *Háden, G.*, Huotilainen, M., Balázs, L., Sziller, I., Beke, A., Fellman, V., Winkler, I. (2007) Auditory temporal grouping in newborn infants. *Psychophysiology* 44 (5), 697-702. DOI: 10.1111/j.1469-8986.2007.00540.x

IV. Ladinig, O., Honing, H., *Háden, G.*, Winkler, I. (2009) Probing attentive and pre-attentive emergent meter in adult listeners without extensive music training. *Music Perception* 26(4), 377-386. DOI: 10.1525/MP.2009.26.4.377

V. Winkler, I., *Háden, G. P.*, Ladinig, O., Sziller, I., Honing, H. (2009) Newborn infants detect the beat in music. *Proceedings of the National Academy of Sciences* 106. 2468-2471. DOI: 10.1073/pnas.0809035106

Selected references

Bregman, A. S. (1990) Auditory scene analysis: the perceptual organization of sound. Bradford Books, Cambridge, MA.

Carral, V., Huotilainen, M., Ruusuvirta, T., Fellman, V., Näätänen, R., Escera, C. (2005) A kind of auditory 'primitive intelligence' already present at birth. .*European Journal of Neuroscience*, 21, 3201–3204.

Cheour, M., Leppänen, P. H. T., Kraus, N. (2000) Mismatch negativity (MMN) as a tool for investigating auditory discrimination and sensory memory in infants and children. *Clinical Neurophysiology* 111, 4-16.

Dowling, W. J. (1978) Scale and Contour: Two Components of a Theory of Memory for Melodies. *Psychological Review*, 85(4), 341-354.

Drake, C. (1993) Reproduction of musical rhythms by children, adult musicians, and adult nonmusicians. *Perception & Psychophysics*, 53(1), 25-33.

Edworthy, J. (1985) Interval and Contour in Melody Processing. *Music Perception* 2(3), 375-388.

Fitch, W. T. (2006) The biology and evolution of music: A comparative perspective. *Cognition,* 100, 173-215.

Handel, S. (2006) Perceptual coherence: Hearing and seeing, Oxford University Press, New York.

Hannon, E. E., Trehub, S. E. (2005) Metrical Categories in Infancy and Adulthood. *Psychological Science,* 16(1), 48-55.

Hauser, M. D., McDermott, J. (2003) Functional brain development in humans. *Nature Neuroscience,* 6, 663-668.

He, C. Hotson, L., Trainor, L. J. (2007) Mismatch Responses to Pitch Changes in Early Infancy. *Journal of Cognitive Neuroscience,* 19(5), 878–892.

Jaffe J., Beebe, B., Feldstein, S., Crown, C. L., Jasnow, M. D. (2001) Rhythms of Dialogue In.: Infancy,Monographs for the Society for Research and Child Development Vol 66, No 2., Blackwell, Boston.

Justus ,T., Hutsler, J. J. (2005) Fundamental Issues in the Evolutionary Psychology of Music : Assessing Innateness and Domain Specificity . *Music Perception*, 23, 1-27.

Krumhansl, C., L. Iverson, P. (1992) Perceptual Interactions Between Musical Pitch and Timbre. *Journal of Experimental Psychology: Human Perception and Performance*. 18(3), 739-751.

Kujala, T., Tervaniemi, M., Schröger, E. (2007) The mismatch negativity in cognitive and clinical neuroscience: Theoretical and methodological considerations. *Biological Psychology*, 74 ,1–19.

Lerdahl, F., Jackendoff, R. (1983). A generative theory of tonal music. MIT Press, Cambridge, MA.

London, J. (2002) Hearing in time. Oxford University Press, New York.

McAdams, S., Winsberg, S., Donnadieu, S., De Soete, G., Krimphoff, J. (1995) Perceptual scaling of synthesized musical timbres: common dimensions, specificities, and latent subject classes. *Psychological Research*, 58(3),177-192.

Näätänen, R., Paavilainen , P., Rinne, T., Alho, K. (2007) The mismatch negativity (MMN) in basic research of central auditory processing: A review. *Clinical Neurophysiology,* 118, 2544–2590.

Paavilainen, P., Jaramillo, M., Näätänen, R., Winkler, I. (1999) Neuronal populations in the human brain extracting invariant relationships from acoustic variance *Neuroscience Letters*, 265 ,179-182.

Peretz, I., Coltheart, M. (2003) Modularity of music processing. *Nature Neuroscience*, 6(7), 688-691.

Phillips-Silver, J., Trainor, L. J. (2005) Feeling the Beat: Movement Influences Infant Rhythm Perception. *Science*, 308, 1430.

Repp, B. H. (2005) Sensorimotor synchronization: A review of the tapping literature. *Psychonomic Bulletin & Review*, 12(6), 969-992.

Semal, C., Demany, L. (1991) Dissociation of pitch from timbre in auditory short-term memory. *Journal of the Acoustical Society of America*, 89(5), 2404-10.

Semal, C., Demany, L. (1993) Further evidence for an autonomous processing of pitch in auditory short-term memory. *Journal of the Acoustical Society of America,* 94(3), 1315-1322.

Sussman, E., Winkler, I., Huoutilainen, M., Ritter, W., Näätänen, R. (2002) Top-down effects on the initially stimulus-driven auditory organization. *Cognitive Brain Research*, 13, 393-405.

Sussman, E., Ritter, W., Vaughan, H.G. (1998) Predictability of stimulus deviance and the mismatch negativity. *NeuroReport*, 9, 4167–4170.

Sussman, E. S., Gumenyuk, V. (2005) Organization of sequential sounds in auditory memory. *NeuroReport*, 16(13), 1519-1523.

Tervaniemi, M., Castaneda, A., Knoll, M., Uther, M. (2006). Sound processing in amateur musicians and non-musicians: ERP and behavioral indices. *NeuroReport*, 17, 1225-1228.

Trehub, S.E., Hannon, E. E. (2006) Infant music perception: Domain-general or domain-specific mechanisms? *Cognition,* 100,73-99.