brain research 1626 (2015) 14–20

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/brainres

Brain Research

Research Report

Predictive processing of pitch trends in newborn infants

Gábor P. Háden[a,*], Renáta Németh[a,b], Miklós Török[c], István Winkler[a,d]

[a]Institute of Cognitive Neuroscience and Psychology, Research Centre for Natural Sciences, Hungarian Academy of Sciences, Magyar Tudósok krt. 2, H-1117 Budapest, Hungary
[b]Department of Cognitive Science, Central European University, Frankel Leó út 30-34, H-1023 Budapest, Hungary
[c]Military Hospital, Department of Obstetrics-Gynaecology and Perinatal Intensive Care Unit, Podmaniczky u. 111, H-1062 Budapest, Hungary
[d]Institute of Psychology, University of Szeged, Egyetem u. 2, H-6722 Szeged, Hungary

ARTICLE INFO

Article history:
Accepted 21 February 2015
Available online 6 March 2015

Keywords:
MMN
Newborn infant
ERP
MMR
Predictive processing
Pitch
Abstract rule

ABSTRACT

The notion of predictive sound processing suggests that the auditory system prepares for upcoming sounds once it has detected regular features within a sequence. Here we investigated whether predictive processes are operating at birth in the human auditory system. Event-related potentials (ERP) were recorded from healthy newborns to occasional ascending pitch steps occurring in the 2nd or the 5th position within trains of tones with otherwise monotonously descending pitch. If the trains were processed in a predictive manner only deviant pitch steps occurring in the later train position would elicit the discriminative mismatch response (MMR). Deviants delivered in the 5th but not in the 2nd position of the tone trains elicited a significant MMR response. These results suggest that newborns represent pitch trends within sound sequences and they process them in a predictive manner.

This article is part of a Special Issue entitled SI: Prediction and Attention.

1. Introduction

Where as the role of attention in perception has been acknowledged since the early days of psychology (e.g., James, 1890), the notion that perception may also be of essentially predictive nature has been only relatively recently considered in a systematic manner (e.g., Gregory, 1980). Some modern theories of perception specify Helmholtz' (1860/1962) theoretical framework of utilizing learned information for disambiguating the sensory input in terms of generative models providing predictionsabout distal objects and their behaviour (e.g., Ahissar and Hochstein, 2004; Creutzig et al., 2009; Friston and Kiebel, 2009;

Abbreviations: ANOVA, analysis of variance; EEG, electroencephalogram; ERP, event-related potential; ISI, inter-stimulus interval; MMN, mismatch negativity; MMR, mismatch response

*Correspondence to: Institute of Cognitive Neuroscience and Psychology, Research Centre for Natural Sciences, Hungarian Academy of Sciences, PO Box 286, H-1519 Budapest, Hungary.
E-mail addresses: haden.gabor@ttk.mta.hu (G.P. Háden), nemeth.renata@ttk.mta.hu (R. Németh), miklos.torok@indamail.hu (M. Török), winkler.istvan@ttk.mta.hu (I. Winkler).

http://dx.doi.org/10.1016/j.brainres.2015.02.048
0006-8993/

Schütz-Bosbach and Prinz, 2007; Winkler et al., 2009). Proponents of the predictive view of perception point out that it can be used to unify theories of perception and action (Friston, 2010; Hohwy, 2007; Hommel et al., 2001; Tishby and Polani, 2011) as well as to guide computational modelling of perceptual decisions (e.g., Hohwy et al., 2008; Mill et al., 2013) and brain responses elicited by unexpected stimuli (e.g., Garrido et al., 2009; Wacongne et al., 2011). Since predictive processing theories follow the empiricist tradition, one may ask whether the predictive principle itself is learned or it is an innate capability of the human brain.

Applying predictive processing principles to auditory perception is especially attractive, because sounds are ephemeral and the patterns formed by them, which are regarded by some as the processing units or perceptual objects in the auditory modality (Kubovy and Van Valkenburg, 2001; Griffiths and Warren, 2004; Winkler, 2010), unfold in time. Predictive processing allows for faster assessment of sensory information (e.g., Bar, 2007; Bendixen et al., 2009), which is essential for the real-time decoding of complex auditory scenes (Bregman, 1990). There is still scarce direct evidence for predictive processing in the auditory system (for a review, see Bendixen et al., 2012). However, the properties of brain responses elicited by deviant auditory events (the mismatch negativity [MMN] event-related potential [ERP]) are generally compatible with the notion that predictions for upcoming sounds are checked against the actual sound input and deviations are processed as prediction errors (Winkler, 2007; Winkler and Czigler, 2012). Auditory deviance-related brain responses (termed the mismatch response [MMR] as they are not full equivalents of the adult MMN, see, e.g., Kushnerenko et al., 2007) have been recorded from newborn infants (Alho et al., 1990; for a review, see Kushnerenko et al., 2013). This allows one to assess whether the neonatal auditory system can detect violations of predictive acoustic regularities.

In adults, two sets of deviance-detection paradigms provide the most compelling evidence for the notion that predictive processes underlie deviance detection: Violations of simple contingent inter-tone relations, such as "if the current sound is long, then the next will be high; if the current sound is short, then the next will be low" (Bendixen et al., 2008; Paavilainen et al., 2007) and those of sensory trends, such as monotonously falling of pitch (Tervaniemi et al., 1994), elicit MMN. Because the responses elicited by violations of inter-tone contingencies have been found to be of rather low amplitude in adults and the signal-to-noise ratio of ERP measurement in neonates is substantially lower than that in adults, we chose to measure in neonates the response to sensory trend violations. Although it is difficult to establish a direct analogy between the adult MMN and the infant MMR (see Trainor, 2012), deviations from both simple and complex pitch regularities have been shown to elicit MMR in newborn infants: e.g., MMR has been elicited by deviations from a repeating pitch (Novitski et al., 2007) irrespective of timbre variance (Háden et al., 2009), by violations of the constancy of the direction (Carral et al., 2005) and size (Stefanics et al., 2009) of pitch change within tone pairs varying in absolute pitch, as well as by rare chords categorically differing from the majority of chords (Virtala et al., 2013).

These previous studies established that neonates encode the direction and size of pitch steps. Thus, it is possible that a series of tones with descending pitch will evoke prediction for the continuation of this trend in newborn infants. If this was the case, violating the pitch trend should elicit an error signal, such as the MMR. To test this possibility, we presented newborn infants with trains consisting of 6 tones descending in pitch in uniform 3-semitone steps ("standard"). Trains started with a pitch randomly taken from the 622 to 1480 Hz pitch range (Fig. 1). Half of the trains contained a tone that was 3 semitones higher in pitch than the previous one ("deviant"). Ascending pitch steps occurred with equal probability either in the 2nd or the 5th position. Because the brain must first extract the descending-pitch regularity before forming a prediction for the continuation of the trend, we expected that MMR to the violation of the pitch trend could be elicited by the late but not by the early ascending-pitch tones. MMR elicitation by deviants at the early position would suggest that the newborn brain was sensitive to the overall probability of ascending vs. descending pitch steps in the stimulus block. No MMR found in either position would suggest that the newborn brain does not detect pitch trends.

2. Results

At Position 2, standard and deviant tones elicited ERP waveforms with their differences peaking at ca. 185 ms and 460 ms from stimulus onset at Cz (Fig. 2). Both differences appeared to be more pronounced over posterior right electrodes. However, no significant main effect or interaction including stimulus-type was obtained in the stimulus-type (deviant vs. standard tone) × frontality (frontal vs. central vs. parietal electrodes) × laterality (left vs. midline vs. right electrodes) ANOVAs separately conducted on the amplitudes averaged from either the 146–226 ms or the 420–500 ms interval.

At Position 5, standard tones elicited a response with an early and late negative peak (note that the second peak followed the onset of the next tone in the sequence), whereas deviant tones elicited a slower positive response with a peak between 200 and 300 ms (Fig. 3). The ANOVA (see structure above) for the early window (93–173 ms) showed a significant main effect of stimulus-type ($F(1, 32)=7.55$, $p=0.009$, $\eta_p^2=0.19$) as well as a significant interaction between stimulus-type, frontality, and laterality ($F(4, 128)=2.58$, $p=0.050$, $\eta_p^2=0.07$, $\varepsilon=0.85$). The interaction was due to more positive ERP responses elicited by the deviant tones over frontal and central midline locations compared to standard tones as shown by a post-hoc Tukey HSD test (df$=128$, $p<0.05$). The ANOVA (see structure above) for the late

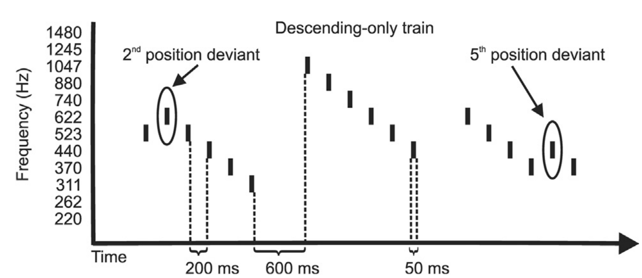

Fig. 1 – Overview of the experimental paradigm with the three types of trains (Descending-only train, 2nd position deviant, 5th position deviant). Frequency levels are shown on the *y*-axis, timing on the *x*-axis.