International Journal of Pediatric Otorhinolaryngology 73 (2009) 751–755

Contents lists available at ScienceDirect

International Journal of Pediatric Otorhinolaryngology

journal homepage: www.elsevier.com/locate/ijporl

Effects of musical training on sound pattern processing in high-school students

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ARTICLE INFO

Article history:
Received 11 December 2008
Received in revised form 27 January 2009
Accepted 1 February 2009
Available online 6 March 2009

Keywords:
Auditory
Event-related potentials (ERPs)
Adolescents
Children
Musicians
Mismatch negativity (MMN)

ABSTRACT

Objective: Recognizing melody in music involves detection of both the pitch intervals and the silence between sequentially presented sounds. This study tested the hypothesis that active musical training in adolescents facilitates the ability to passively detect sequential sound patterns compared to musically non-trained age-matched peers.
Methods: Twenty adolescents, aged 15–18 years, were divided into groups according to their musical training and current experience. A fixed order tone pattern was presented at various stimulus rates while electroencephalogram was recorded. The influence of musical training on passive auditory processing of the sound patterns was assessed using components of event-related brain potentials (ERPs).
Results: The mismatch negativity (MMN) ERP component was elicited in different stimulus onset asynchrony (SOA) conditions in non-musicians than musicians, indicating that musically active adolescents were able to detect sound patterns across longer time intervals than age-matched peers.
Conclusions: Musical training facilitates detection of auditory patterns, allowing the ability to automatically recognize sequential sound patterns over longer time periods than non-musical counterparts.

1. Introduction

Musical training is known to alter sound perception in both children and adults. Those with musical training can detect slight pitch and duration violations in music and speech more accurately [1–3], and faster [4–6] than non-musicians, and are better than non-musicians at reproducing the order of a three-tone sequence [7]. Effects of musical training are long-lasting, modulating cortical structure and functions [8–10]. Musicians have higher gray matter volume in motor, auditory, and visual-spatial brain regions compared to non-musicians [11–13], and have been found to have higher concentrations of Nacetylaspartate (NAA) in a brain area associated with music perception (left planum temporale), which correlated with the duration of musical training [14].

The goal of the current study was to evaluate long-lasting effects of musical training in adolescents, by testing the hypothesis that musical training increases the acuity of auditory pattern processing skills, which can be indexed by neurophysiological measures when listeners have no immediate task with the sounds (i.e., passive detection). Perception of musical melody involves detection of temporal sound patterns. Both the pitch intervals and the silence between sequentially presented sounds are encoded. We previously investigated the effect of time on pattern processing as indexed by neurophysiological measures in adults, using a sequentially repeating tone pattern [15]. These results showed that in adults, passive grouping of the tone sequence, indexed by neurophysiologic measures, occurred only when presented at a rapid rate (200 ms stimulus onset asynchrony, SOA). When the same repeating pattern was presented at longer SOAs (400, 600, and 800 ms), there was no neurophysiological indication of the pattern: each tone was processed as an individual unit. Though this study provided some insight in how temporal spacing affected non-musician adults, the question of how musical training affects pattern processing in children has largely been unexplored. Particularly, there is scant literature focused on adolescent abilities in auditory processes. Given the changes in brain structure and function in adult musicians, we hypothesized that active musical training would facilitate the ability to passively detect sequential sound patterns over longer periods of time in adolescents compared to non-musical age-matched peers.

To examine this question, we used the paradigm of Sussman and Gumenyuk [15]. Two tones were presented in a fixed order (XXXXOXXXXO..., where 'X' has a different frequency value than 'O') to determine when the five-tone pattern was detected (Fig. 1).

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doi:10.1016/j.ijporl.2009.02.003

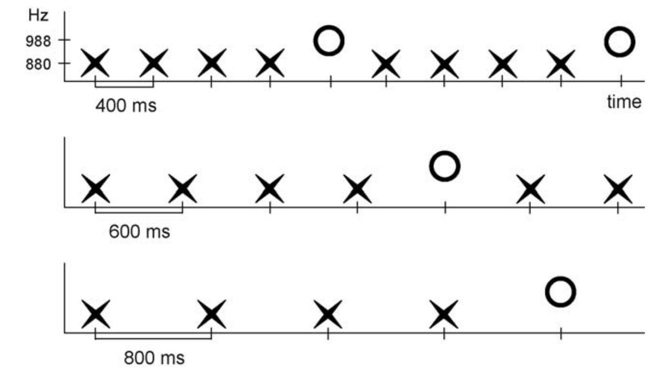

Fig. 1. Schematic diagram of the stimulus paradigm. The three conditions of stimulus onset asynchrony (SOA, onset-to-onset) are shown: 400 ms SOA (top row), 600 ms SOA (middle row), and 800 ms SOA (bottom row). The 'X' represents a tone of 880 Hz, and the 'O' represents a tone of 988 Hz. Time is shown on the *x*-axis and frequency value on the *y*-axis.

The mismatch negativity (MMN) component of event-related potentials (ERPs) was used to physiologically index deviance detection. When the repeating pattern is detected, there is no 'deviant' in the sequence and thus, MMN is not elicited by the infrequent 'O' tone in the pattern [15–17]. However, when the repeating pattern is not detected, the infrequent 'O' tone is detected as an 'oddball', and elicits MMN. Thus, in the SOA conditions that MMN is elicited, we conclude there was no passive grouping of the sounds into melodic sequences.

2. Methods

2.1. Participants

Twenty healthy adolescents aged 15–18 years old participated in the study. All participants passed a hearing screening (thresholds ≤20 dB HL for pure tones at 500, 1000, 2000, and 4000 Hz bilaterally) and were paid for their participation ($10 per hour). Participants under 18 years old gave assent and their guardians/parents or participants over 18 years old gave consent for participation. A questionnaire regarding musical training was given prior to testing to determine group placement as 'musician' or 'non-musician' (Table 1). Ten participants were defined as 'musicians' (M = 16 years, 5 months), and 10 as 'non-musicians' (M = 17 years). If the participant was actively involved in a music group or classes at the time of testing, then he/she was defined as a 'musician'. Those who did not participate in any music group or classes were defined as a 'non-musician'. Thus, all participants had some musical exposure.

Table 1
Mean (S.D.) and sum of responses to the musical training questionnaire.

	Non-musicians	Musicians
N	10 (5 M)	10 (5 M)
Age	17y 0m (7m)	16y 5m (7m)
Handedness	9 R	10 R
Age learned to read music	7y 9m (1y 10m)	7y 6m (1y 9m)
Age began playing	9y 2m (2y 6m)	9y 6m (3y 4m)
Reads music	6	10
Number of musician relatives	1	3
Number of years playing	4y 0m (2y 6m)	5y 6m (3y 3m)
Involved in school music groups	0	8
Involved in outside music groups/classes	0	10
Self-categorization as musician	2	10
Hours/week spent playing	0.5 h (1 h)	8 h (3 h)
Hours/week listens to music	15 h (17 h)	32 h (48 h)

M = male, y = year, m = month, R = right.

2.2. Stimuli

Stimuli were created using Neuroscan software (STIM, Compumedics, Corp., Charlotte, NC). Two pure tones (50 ms duration, 7.5 ms rise/fall time) were presented bilaterally through insert earphones (E-A-R-tone 3A®) in a fixed order. Sound level (75 dB SPL) was calibrated using a sound level meter (Brüel & Kjær 2209). The tone order created a five-tone pattern when repeated (XXXXOXXXXO... Fig. 1 and [15]). The 'X' tone had a frequency of 880 Hz and the 'O' tone 988 Hz. The five-tone pattern (XXXXO) was presented 240 times successively, with no breaks between patterns, separately in three conditions of SOA (400, 600, 800 ms). There were 1200 tones presented in each condition.

2.3. Procedures

Participants sat in a comfortable chair in front of a TV monitor during the experiment, and watched a captioned, silent video and had no task with the sounds. The three conditions of SOA (400, 600, 800 ms), presented separately, were counterbalanced across subjects using a Latin Squares design. The total session time was approximately 2 h, which included electrode cap placement and breaks.

2.4. Electroencephalogram (EEG) recording and data reduction

EEG was recorded with an electrode cap from the following electrode sites: Fpz, Fp1, Fp2, Fz, F3, F4, F7, F8, FC1, FC2, FC5, FC6, Cz, C3, C4, CP1, CP2, CP5, CP6, T7, T8, Pz, P3, P4, P7, P8, Oz, O1, O2 (10-20 system) and the left and right mastoids (LM and RM). Fp1 and an electrode placed below left eye were used to monitor the vertical electrooculogram (EOG). An electrode placed on the tip of the nose was the reference and PO9 was used as the ground electrode. EEG and EOG was digitized with a 1000 Hz sampling rate (0.05–200 Hz band pass), and then filtered off-line between 1 and 15 Hz. Epochs were 600 ms starting 100 ms before stimulus onset (−100 to 500 ms). Artifact rejection criterion was set at ±100 μV on all electrodes after baseline correcting to the whole epoch. The 'standard' ERP was obtained by averaging together the responses elicited by the 2nd–4th 'X' tones of the pattern. The 'deviant' ERP was obtained by averaging together the response to the 5th 'O' tone of the pattern. The response to the 1st tone of the pattern was excluded from analyses, so not to include refractory effects on responses to the standard following the deviant. MMN was delineated in the difference waveforms, obtained by subtracting the ERP elicited by the standard ('X') from the ERP elicited by the deviant ('O').

2.5. Data analysis

The peak latencies of the obligatory ERP components (e.g. P1, N1, P2 and N2) were identified using Global Field Power (GFP) analysis [18], and then mean amplitudes were measured using the standard waveform from each condition in a 40 ms window centered on the peak, using electrode sites that provide the greatest signal to noise ratio in adolescents (Fz, Cz, FC1, FC2, C3, and C4; [19]). The MMN peak latency was also identified using GFP, on the grand-mean difference waveform. The mean amplitude was then measured using a 40 ms window centered on the peak at Fz. One-sample, one-tailed t-test was used to determine the presence of MMN. Mixed mode repeated-measures ANOVA with factors of group (musicians vs. non-musicians), condition (400, 600, 800 ms SOA), and electrode (Fz, Cz, FC1, FC2, C3, C4) was used to compare latency and amplitude of the obligatory ERP components. Separate