Investigating the Relationship of Music and Language in Children

Influences of Musical Training and Language Impairment

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ABSTRACT: Language and music are human universals involving perceptually discrete elements organized in hierarchically structured sequences. The set of principles governing the combination of these structural elements into sequences is known as *syntax*. A violation of expectancies concerning syntactic regularities may be reflected by two ERP components: the ERAN (early right anterior negativity) and the ELAN (early left anterior negativity). The ERAN is evoked by a violation of musical regularities, whereas the ELAN is linked to syntax processing in the language domain. There is evidence from adult data to suggest that both ERAN and ELAN are, at least partly, generated in the same brain regions. Therefore, it seems plausible to expect transfer effects between music and language due to shared processing resources. Moreover, the ERAN is larger in adults with formal musical training (musicians) than in those without, indicating that more specific representations of musical regularities lead to heightened musical expectancies. The aim of this study is to investigate these issues in child development. We conducted two experimental sessions with the same participants and compared children with and without musical training (11 years old) and children with or without language impairment (5 years old). In a music experiment, the reactions to chord sequences ending either with a (regular) tonic or with an (irregular) supertonic were compared. For a language experiment we used syntactically correct and incorrect sentences. Preliminary results show that an ERAN is present in both groups and appears to have a larger amplitude in musically trained children. In addition, there are indications of an enhanced negativity in response to a syntactic violation in the musically trained children. The relationship between the ERP components is, moreover, manifested in the finding that an ERAN is present in linguistically nonimpaired children at the age of 5 years but not in children with language impairment of the same age.

KEYWORDS: processing of linguistic and musical syntax; development; musical training; language impairment; event-related brain potential (ERP); ERAN; ELAN

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INTRODUCTION

Music is one of the oldest and most basic sociocognitive domains of the human species. It is assumed that human musical abilities played a key phylogenetical role in the evolution of language and that music-making behavior covered important evolutionary functions such as communication, group coordination, and social cohesion.[1] Because the perception and, even more, the production of music involves practically every congnitve function, music has proven itself as a valuable tool for the investigation of the functional organization of the human brain.[1]

Natural environments contain highly structured systems, such as language and music, to which we are exposed in everyday life. The human brain internalizes regularities of these systems by passive exposure, and the acquired implicit knowledge influences perception and performance. Language and music provide two instances of highly structured systems that may be learned in an incidental manner and used in adults in an elaborate fashion. They consist of perceptually discrete elements organized in hierarchically structured sequences. The combination of these structural elements into sequences is governed by a set of principles that may be denoted as syntax.[2]

Few studies have examined the relationship between music and language processing. Musical expectancies are automatically generated during the perception of a musical context.[3–6] These expectancies are most presumably established with reference to a complex system of regularities (of major–minor tonal, or “classical” Western music) that build a musical structure and have been considered to represent part of a musical syntax.[7–9] A fruitful approach to investigate the processing of language and music are event-related brain potentials (ERPs). Processing of musical syntax was investigated in ERP studies that compared the responses evoked by harmonically inappropriate versus appropriate chords. A violation of musical regularities has been shown to be reflected in an early right anterior negativity (ERAN), that can be elicited preattentively.[10–12] Usually, the ERAN is followed by a late negativity, the N5 (maximal around 500–550 ms), which is supposed to reflect processes of musical integration.[10,11] Furthermore a late positive component has been described, which is thought to be evoked by detectional processes of a music-structural violation.[13]

With respect to effects of musical expertise on music perception in adults, a previous EEG study indicated that musicians react more sensitively to music-syntactic irregularities than nonmusicians.[14] The ERAN is larger in subjects with extensive formal musical training, suggesting that more specific representations of musical regularities lead to a stronger violation of musical expectancies.

Most previous ERP studies investigating music perception have been conducted with adults. Thus, the aim of this study is to specify in more detail how the neural correlates reflecting music processing develop during childhood. Previous studies investigating processing of musical structure in children with EEG[15] and fMRI[16] suggest that even five-year-old children show comparable processing mechanisms to adults. These studies indicate that children process chords according to their harmonic appropriateness, that is, according to a cognitive representation of the major–minor tonal system.

Research on language processing using ERPs found the early left anterior negativity (ELAN) and the late positivity (P600) as markers for syntactic processes.[17,18]

It is assumed that the ELAN reflects automatic initial structure building, which involves the identification of the incoming word's syntactic category upon which a local syntactic structure is built.[17–19] The syntactic structure not only provides the parsing system to build up structural hierarchies and relationships among various phrases, but it also allows more information to be kept in memory. The P600 is thought to reflect secondary parsing processes (under strategic control), including reanalysis and repair, depending on whether the sentence under consideration has a correct, but nonpreferred structure, or an incorrect structure.[18,19]

Behavioral and ERP studies show that, although children are able to comprehend sentences during early childhood, the mechanisms they use to achieve comprehension are different in early childhood and gradually develop through late childhood. The younger the age, the more children rely on contextual information. This is evidenced in a larger N400 in younger children[20] and in context-dependent monitoring times for function words in younger age groups.[21] Syntactic processes, by contrast, are not established as contextually independent (encapsulated), automatic processes before late childhood. This is supported by the context-dependent monitoring times for function words[21] and, moreover, by the ERP finding that only 8- to 10-year old nonimpaired children, but not developmentally delayed children, demonstrate a left lateralized negativity for function words.[22] These studies provide first indications regarding the developmental changes in the process of language comprehension and possibly in its neural basis. The age at which the ELAN can be observed depends upon the type of linguistic material used. For sentences with passive mode construction, also used in the present study, an ELAN appears at twelve to thirteen years of age; in younger children, however, a later, sustained negativity in response to a syntactic violation may be found.[23] For sentences with active mode construction, an ELAN can be found even in 32-month-old children.[24]

As stated previously, violations of the musical and linguistic syntax may be reflected in two ERP components: the ERAN, which is a response to a violation of the musical structure, and the ELAN, which reflects the detection of a linguistic syntax violation. These ERP components share several properties: both are negativities most prominent over frontal leads; they appear in a comparable time range with a maximum amplitude approximately 200 ms after stimulus onset; and they reflect very fast and automatic structure-building processes. They differ, however, in the laterality of the scalp distribution: processing of linguistic syntax is more lateralized to the left hemisphere, and processing of musical structure is more lateralized to the right hemisphere.

Most relevant to the present topic is that ERAN and ELAN are generated in comparable regions of the brain. Source localizations with MEG detected the sources of ERAN and ELAN in the inferior frontal cortex and suggest that neural correlates of music syntactic processing are, at least partly, located in the inferior frontolateral cortex (inferior pars opercularis)[25] and in the anterior superior temporal gyrus (STG).[7] These areas are also involved in the syntactic analysis of speech. Like the ERAN, the ELAN is thought to be generated in the inferior frontolateral cortex and in the anterior STG.[24] Comparable brain regions were found to be activated in experiments using fMRI when examining the neural bases of processing linguistic and musical syntax. Specifically areas in the inferior frontolateral parts of the brain were found to be activated in music as well as in language, but with a slightly different hemispheric weighting.[16,27–29] These studies indicate that both kinds of processes may share some common underlying neural substrate and that ERAN and ELAN are generated in comparable regions of the brain. Because of this and the close relationship between ERAN and ELAN, one might expect transfer effects between the two domains.

Taken together, this has led to three main topics of investigation for this study: First, we were interested in how violations of musical and linguistic syntax will be processed in different age groups. Second, we wanted to know whether there is a difference in ERAN and ELAN between children with and without musical training and with or without language impairments. Finally, we were interested in whether one could find a transfer due to additional musical training and if language impairment leads to a difference in the neural processing of musical structure. In order to address these issues, we conducted a within-subject comparison of ERAN and ELAN in children of different ages and took EEG measurements in experiments investigating either a violation of musical structure or of linguistic syntax.

MATERIALS AND METHODS

Children from two age groups participated in our studies. All were right-handed,[30] native speakers of German and had no known hearing or neurological deficits, attentional deficit disorders, or reading or learning disabilities.

The first group consisted of 28 children around 11 years of age. The 14 children who had received musical training were recruited from the Saint Thomas Boys Choir and the public music school (10 years, 2 months to 11 years, 6 months old, mean = 10 years, 10 months; 7 male, 7 female). The 14 children without musical training came from public schools in Leipzig (10 years, 4 months to 11 years, 11 months old, mean = 11 years, 2 months; 8 male, 6 female). There was no group difference in the results of the verbal part of the Wechsler Intelligence Scale for Children (HAWIK-III).[31] Even though the mean in the group of musically trained children (122.43, SE = 3.30) was slightly higher than in the group of the non–musically trained children (121.36, SE = 2.82), this difference was not significant ($t_{(26)} = 0.25$, $P = 0.807$). Moreover the two groups did not differ in duration with regard to their parents' education.

The second group consisted of 24 children around 5 years of age. Twelve of them had a specific language impairment (4 years, 2 months to 5 years, 11 months old, mean = 5 years, 3 months; 6 boys, 6 girls) and were evaluated at a kindergarten for special education. The 12 children (4 years, 3 months to 6 years, 3 months old, mean = 5 years, 4 months; 6 boys, 6 girls) without language impairment were recruited from public nursery schools in Leipzig. Children were only included if parents and teachers reported normal hearing and if they had at least 70 IQ points measured by the nonverbal part of the Kaufman Assessment Battery for Children.[32]

EEG data were recorded with Ag-AgCl electrodes from 25 scalp locations, referenced to the left mastoid, in an experiment that examined either a violation of musical syntax or of linguistic syntax. Processing of EEG data was conducted with EEGLab 4.512.[33] ERPs were evaluated statistically by computing two regions of interest (ROIs): left-frontal (F3, FC3) and right-frontal (F4, FC4). Because of a more posterior scalp distribution of the ERAN in the 5 year olds, different ROIs were used for that age group: left-anterior (F3, FC3, C3) and right-anterior (F4, FC4, C4).

Variances of ERPs were analyzed by general linear models (GLMs) for repeated measurements. These analyses are preliminary due to the small sample size and the need for additional subjects.

For the music experiment we employed two types of chord sequences that consisted of five chords. The first four chords were arranged according to the classical rules of harmony and established a musical context toward the end of the sequence. They were always the same: tonic, subdominant, supertonic and dominant. The fourth chord induced a strong expectancy for a tonic chord at the fifth position of a sequence,[3–5,34] as the dominant–tonic progression (i.e., the progression of chords built on the fifth and on the first scale tone) at the end of a chord sequence is a prominent marker for the end of a harmonic sequence and has been considered as a basic syntactic structure of major–minor tonal music.[35] The last chord was thus either a regular tonic, or an irregular supertonic, which in the case of the latter violated the expectancy of a regular musical structure.

The chord sequences were transposed to all twelve keys and were repeated eight times, leading to 96 sequences for each condition. Furthermore there were 18 sequences consisting of one chord played by another instrument. The task for the participants was to react to this different instrumental timbre with a keypress.

Stimuli of the language experiment were sentences in which four words had the same grammatical function, that is, each of the sentences consisted of an article, a noun, an auxilliary, and a past participle. Similar sentences had been used in several experiments before.[17,18,23] The correct sentences consisted only of these four words (e.g., Die Tante wurde geärgert. [The aunt was angered.]). A syntactic violation was introduced by sentences in which a preposition appeared after the auxiliary and was directly followed by a past participle (e.g., Die Mutter wurde im geärgert. [The mother was angered in.]) leading to a phrase structure error. Because the preposition indicates the beginning of a prepositional phrase, necessarily consisting of a preposition and a noun phrase, this sequence of words created a clear word category violation. Filler sentences that consisted of a whole prepositional phrase (i.e., preposition followed by a noun phrase) were introduced to ensure that participants would not necessarily anticipate a violation when encountering a preposition (e.g., Der Onkel wurde im Bett geärgert. [The uncle was angered in the bed.]). These sentences were not evaluated. In the experiment, we used 96 correct, 96 incorrect, and 48 filler sentences. Most of the sentences were read by a female speaker, but in 32 sentences one word was replaced by a word spoken by a male voice. The task here was to detect the change in the voice timbre.

RESULTS

The results from the music experiment with the 11 year olds are shown in FIGURE 1 (see figure caption for explanation). In the music experiment a considerable difference between the two conditions, maximal around 190 ms, became evident in musically trained as well as in non–musically trained children (see FIGS. 1A and 1B). The time window for statistical analyses was centered around that maximum (140 to 240 ms). The mean for the difference is –2.20 μV (SE = 0.57; mean of both frontal ROIs and for all subjects). Furthermore the difference in the amplitude of the ERAN is more pronounced in the group of the musically trained children (mean = –3.30 μV;

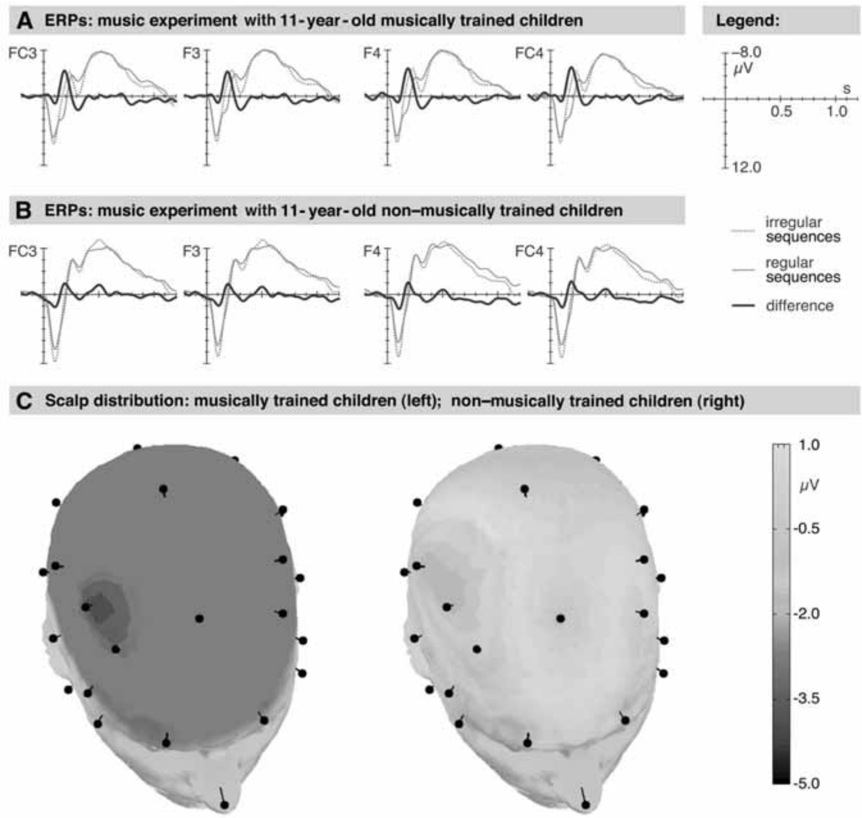

FIGURE 1. Results from the music experiment with 11-year-old children. (**A**) ERPs of the musically trained children. (**B**) ERPs of the non–musically trained children. (**A** and **B**) For the sake of simplicity, only the electrodes of the frontal ROIs are presented. The *solid gray lines* represent the responses to regular chords at the end of a sequence; *dotted gray lines* represent the responses to irregular chords. The *solid black lines* show the difference between the two conditions. (**C**) Scalp distributions of the differences between the two conditions (used time range is 180 to 200 ms). The results of musically trained children are shown on the *left*; the results of the non–musically trained children are shown on the *right*.

SE = 0.61) compared to the non–musically trained children (mean = –1.11 μV; SE = 0.90; see FIG. 1A vs. 1B). We observed a more right-lateralized scalp distribution of the ERAN (see FIG. 1C). The amplitude difference was more pronounced over the right hemisphere (mean = 2.41 mV; SE = 0.60) than over the left hemisphere (mean = 2.00 mV; SE = 0.57). Analyses that are preliminary due to the small sample size were carried out in a GLM with the within-subject-factors condition (supertonic vs. tonic) and hemisphere (left-frontal vs. right-frontal ROI) and the between-subjects-factor group (musically trained or nonmusically trained). The large amplitude difference between the two conditions is reflected in a significant main effect of condition ($F_{(1,26)} = 16.48$; $P < 0.001$). The interaction of condition and group is approaching significance ($F_{(1,26)} = 4.08$; $P = .054$).

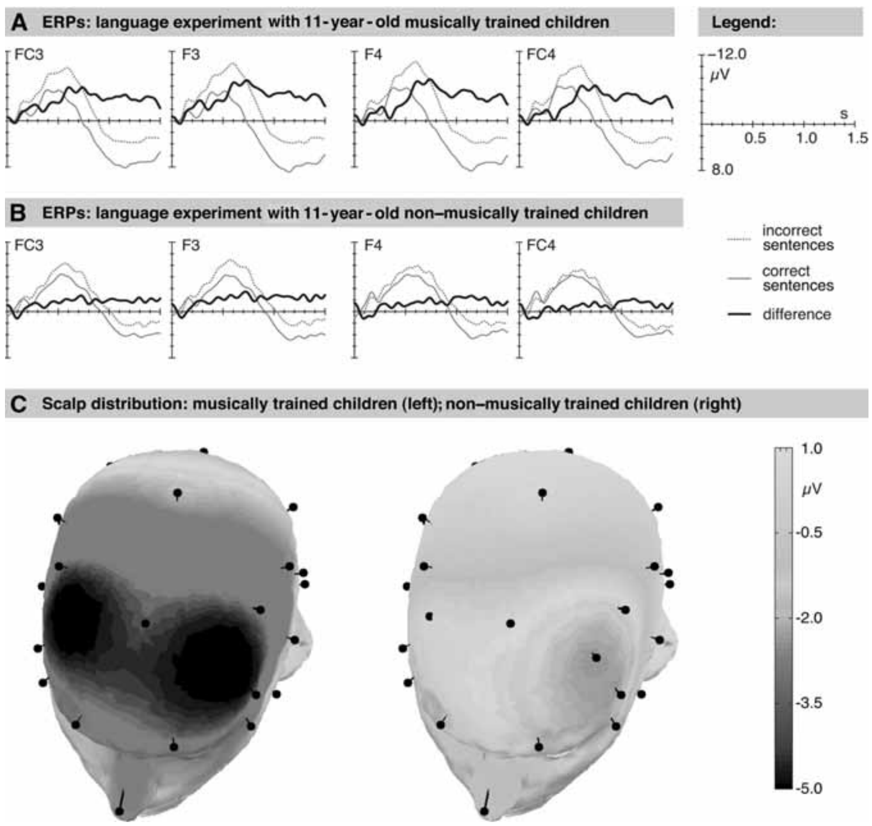

FIGURE 2. Results from the language experiment with 11-year-old children. (**A**) ERPs of the musically trained children. (**B**) ERPs of the non–musically trained children. (**A** and **B**) Responses to the syntactically correct sentences are plotted with *solid gray lines*; those to the syntactically incorrect sentences plotted with *dotted gray lines*. The *solid black lines* show the differences between the two conditions. (**C**) Scalp distributions of the differences between the two conditions (used time range is 500 to 1000 ms). The results of musically trained children are shown on the *left*; the results of the non–musically trained children are shown on the *right*.

The results from the language experiment for the 11 year olds are shown in FIGURE 2 (see figure caption for explanation). There is an amplitude difference between the two conditions (solid black lines) from around 200 ms to 350 ms, and from around 500 ms to 1500 ms. Time windows for statistical analyses were 220 ms to 320 ms for the earlier difference (which may be a precursor of the ELAN) and 500 ms to 1500 ms (for the later, sustained negativity in response to the syntactic violation). For the earlier time range the mean of the difference of the two conditions is –1.72 μV (SE = 0.65; mean of both frontal ROIs and for all subjects). Again the difference in the amplitude is more pronounced in the group of the musically trained children (mean = –2.24 μV; SE = 0.73) compared to the non–musically trained children (mean = −1.20 μV; SE = 1.08; see FIG. 2A vs. 2B). The amplitude difference is larger over the left hemisphere (mean = –2.17 μV; SE = 0.67) than over the right hemisphere (mean = –1.27 μV; SE = 0.68). Tested by means of a GLM with the within-subject-factors condition (syntactically correct vs. incorrect sentences) and hemisphere (left-frontal vs. right-frontal ROI) and the between-subjects-factor group (musically trained vs. non–musically trained children), this leads to a significant main effect of condition ($F_{(1,26)} = 6.94$; $P = 0.014$) and an interaction of condtion and hemisphere ($F_{(1,26)} = 5.72$; $P = 0.024$). Even though the two groups have distinct amplitude differences, this was not reflected in a significant interaction of condition by group. Future research will show these distinct amplitude differences, if such an interaction exists, when a larger group of subjects is used.

For the later time range (the negativity in response to the syntactic violation) the mean difference of the two conditions has a larger amplitude than that of the early negativity (–3.24 μV; SE = 0.69; mean of both frontal ROIs and for all subjects). The difference between the two groups is also larger than for the early negativity: it is –4.77 μV (SE = 0.92) for the musically trained children compared to −1.71 μV (SE = 0.87) in the children without musical training (see FIG. 2A and 2B). The scalp distribution of the difference is more bilateral (see FIG. 2C); it is only slightly larger over the left (−3.43 μV; SE = 0.70) compared to the right hemisphere (−3.05 μV; SE = 0.70). A GLM with the factors condition, hemisphere, and group revealed a significant main effect of condition ($F_{(1,26)} = 26.12$, $P < 0.001$) and an interaction of condition by group ($F_{(1,26)} = 5.81$; $P = 0.023$).

The results of the music experiment in the 5 year olds are shown in FIGURE 3 (see figure caption for explanation). An ERAN could be found in the children who are linguistically nonimpaired, whereas no such response can be seen for the language impaired children (see FIG. 3A vs. 3B). The amplitude of this response is maximal around 230 ms and therefore slightly later than in the older age group. Thus the time

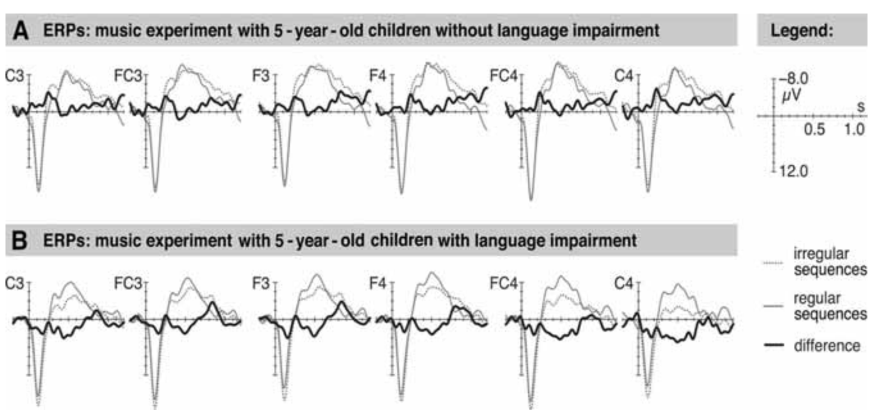

FIGURE 3. Results from the music experiment with 5-year-old children. (**A**) ERPs of the linguistically nonimpaired children. (**B**) ERPs of the language-impaired children. (**A** and **B**) The *solid gray lines* depict the responses to regular chords at the end of a sequence; the *dotted gray lines* depict responses to irregular chords. The *solid black lines* show the difference between the two conditions.

window was 180 to 280 ms after stimulus onset. In addition, the scalp distribution of the maximum amplitude for the difference of the responses on supertonics compared to tonics is weighted more posteriorly than in the older children. Therefore ROIs were computed of F3, FC3, C3 (left-anterior ROI), and F4, FC4, and C4 (right-anterior ROI). The mean amplitude of the difference between the two conditions is present in the linguistically nonimpaired (–3.10 μV, SE = 1.17) but not in the language-impaired children (1.14 μV, SE = 1.26). In the linguistically nonimpaired children the response is more prominent over the right-anterior ROI (mean = –3.50 μV; SE = 1.29) than over the left-anterior (mean = –2.69 μV; SE = 1.31). In the language-impaired children there is almost no response—none in the left-anterior (mean = 0.97 μV; SE = 1.19) and none in the right-anterior ROI (mean = 1.30 μV; SE = 1.48). In a GLM with the within-subject-factors hemisphere (left-anterior vs. right-anterior ROI) and condition (supertonic vs. tonic) and the between-subjects-factor group (language impaired vs. linguistically nonimpaired children), a condition-by-group-interaction is found ($F_{(1,22)} = 6.02$; $P = .023$), but no other main effects or interactions are significant.

DISCUSSION

In our ERP study we investigated processes during auditory sentence comprehension and music perception in children of two different age groups. We found that a violation of harmonic expectancies and linguistic syntax led either to an ERAN or to a later, sustained negativity in response to a syntactic violation. Furthermore we found differences between children with and without musical training and in linguistically nonimpaired compared to language-impaired children when carrying out these processes.

The results indicate that musical training facilitates the processing of musical structure. This is in accordance with earlier studies evidencing a comparable effect for adults.[14] Interestingly this difference was found as early as 11 years when children have not played an instrument for longer than 4 or 5 years. Despite such a relatively short period of musical training, these children may have acquired specific representations of music-syntactic regularities (e.g., more implicit and explicit knowledge about the theory of harmony underlying Western tonal music, and more specific representations of harmonic relatedness).[36]

A characteristic of the ELAN, of which a precursor was found in the language experiment, is a larger amplitude difference over the left hemisphere. This difference in ELAN amplitude between the group of the musically trained and the non–musically trained children is approaching significance, and is expected to become significant with a larger group of participants. Moreover, a later, sustained negativity was found in both groups with an enhanced amplitude in the group with musical training. This indicates a positive transfer from the music to the language domain. This finding was expected, since the neural resources underlying the processing of musical and linguistic syntax overlap to some extent, as outlined in the introduction. The fact that the negativity in response to the syntactic violation is distributed bilaterally is in accordance with an earlier study, which showed the same pattern of results: a bilateral anterior negativity between 600 and 1500 milliseconds.[23]

There are not many studies that investigated transfer effects from music to other cognitive domains. One of these studies investigated influences of musical training on the processing of prosody in language and of melody in music.[37] This study reported an increased N400 in nonmusicians, indicating that they rely more on semantic information when processing prosody. In contrast, there was an early negativity found for the musicians that might reflect the detection of incongruities in melodic and prosodic patterns. Other studies tested potential transfer effects in behavioral experiments (for an overview, see Schellenberg in this volume). Furthermore, there is a substantial body of evidence that suggests that sophisticated processing of musical elements of speech (e.g., prosody) is of considerable importance for the acquisition of language.[38–41]

Finally, no ERAN could be found for the 5 year olds with specific language impairment (SLI), whereas an ERAN could be seen in linguistically nonimpaired children. The finding that an ERAN is present even at that age is in accordance with an earlier study.[15] The difference between the studies is that the chord sequences used in the present study represent a more subtle violation than the Neapolitan chords used in that study. Both studies show that children at that age are able to process musical structure. This is particularly noteworthy because it was previously believed that the acquisition of the rules of "Western" music (which may be considered as a process of culture-specific attunement) is anything but rapid and that sensitivity to culture-specific details of tonal and harmonic structure seems to emerge between 6 and 7 years of age.[42,43] The difference between this assumption and our results might be due to two factors: First, it may be that chord sequences represent clearer irregularities than the melodies used in other studies. Second, the EEG might be a more sensitive method to investigate what processes children are capable of.

The finding that the amplitude of the ERAN is diminished in language-impaired children indicates that they have difficulties when processing musical syntax. There are studies reporting grammatical deficits as characteristic of specific language impairment (SLI).[44–47] Specifically, it seems that children with SLI have difficulties with the comprehension of specific types of syntactic relationships and with the processing of configurational aspects of grammar.[48] Our results fit well with the assumption of grammatical deficits, especially if one bears in mind that the neural correlates of syntax processing in language and music are (at least to some extent) shared by the two domains.

We observed indicators for an intricate relationship of syntax processing in language and music. Even though the analyses of our data are still preliminary, the data suggest that children can profit from musical training because of a more efficient processing of musical structure and because of its impact on the processing of linguistic syntax. This relationship might be especially important as well in therapy for language-impaired children.

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