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Statistical learning and auditory processing in children with music training: An ERP study

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HIGHLIGHTS

- Musically trained children performed better at auditory but not visual statistical learning.
- Musically trained children also showed larger changes in online statistical learning ERPs.
- Individual differences in musical abilities are associated with capacity for statistical learning.

ABSTRACT

Objective: The question whether musical training is associated with enhanced auditory and cognitive abilities in children is of considerable interest. In the present study, we compared children with music training versus those without music training across a range of auditory and cognitive measures, including the ability to detect implicitly statistical regularities in input (statistical learning).
Methods: Statistical learning of regularities embedded in auditory and visual stimuli was measured in musically trained and age-matched untrained children between the ages of 9–11 years. In addition to collecting behavioural measures, we recorded electrophysiological measures to obtain an online measure of segmentation during the statistical learning tasks.
Results: Musically trained children showed better performance on melody discrimination, rhythm discrimination, frequency discrimination, and auditory statistical learning. Furthermore, grand-averaged ERPs showed that triplet onset (initial stimulus) elicited larger responses in the musically trained children during both auditory and visual statistical learning tasks. In addition, children's music skills were associated with performance on auditory and visual behavioural statistical learning tasks.
Conclusion: Our data suggests that individual differences in musical skills are associated with children's ability to detect regularities.
Significance: The ERP data suggest that musical training is associated with better encoding of both auditory and visual stimuli. Although causality must be explored in further research, these results may have implications for developing music-based remediation strategies for children with learning impairments.

1. Introduction

There is growing evidence that musical training is associated with benefits in not only auditory-related tasks but also other non-trained tasks. For example, musical training is associated with benefits in cognitive processing tasks such as memory, attention, and intelligence (Ho et al., 2003; Strait et al., 2010; Schellenberg, 2011). Some of these effects can also be observed in children who are learning music. For instance, it has been reported that children with music training have enhanced skills in a variety of tasks such as pitch perception (Magne et al., 2006), non-verbal reasoning (Forgeard et al., 2008), executive functions (Moreno et al., 2011), and language-related tasks (Anvari et al., 2002; Moreno et al., 2009; Tsang and Conrad, 2011). In addition, previous studies

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have reported evidence of plasticity in brain structure and functioning in children with musical experience. When compared to a control group, children with music training had larger auditory evoked potentials (Shahin et al., 2004), larger anterior corpus callosum (Schlaug et al., 2009), as well as larger right precentral gyrus and right primary auditory cortex (Hyde et al., 2009).

Some have suggested that there might be evolutionary links between music and language in the brain (Wallin and Merker, 2001), with considerable overlap between neural structures involved in encoding and perception of music and language (Patel, 2011). Furthermore, both music and language consist of perceptually discrete elements that are combined into structured sequences according to highly complex regularities. It is therefore of interest to investigate if musical experience is associated with processes that facilitate language acquisition. One such cognitive process that facilitates language acquisition is implicit learning of statistical regularities – statistical learning (SL). The term SL was proposed by Saffran et al. (1996a) to describe infants' ability to identify word boundaries solely from the statistical relationships between syllables in a continuous stream of pseudo-speech. In a series of studies, Saffran and colleagues showed that adults and infants were able to implicitly segment a continuous stream of speech by identifying statistically coherent units (i.e., adjacent units which exhibit strong statistical relationships such as high transitional probability of co-occurrence)(Saffran et al., 1996a,b). A large body of research in implicit learning has focussed on how knowledge of language and music structures may be acquired implicitly (for reviews see Ettlinger et al., 2011; Rohrmeier and Rebuschat, 2012). In contrast, there is a relatively small body of work on direct comparison of SL abilities in musically trained and untrained individuals. Furthermore, studying these processes in individuals with developing music skills (e.g., children who are participating in musical training) can help us to understand the potential correlates of music practice in other domains of cognition.

Cross-sectional research comparing SL in adult musicians and non-musicians has shown mixed results. Some studies have not shown any group differences on behavioural SL tasks (François and Schön, 2011; Paraskevopoulos et al., 2012) whereas others have shown that adult musicians perform better than non-musicians (Romano Bergstrom et al., 2012; Shook et al., 2013). More recently, Mandikal Vasuki et al. (2016) showed that adult musicians outperformed non-musicians on auditory but not visual statistical learning tasks. Research utilizing electrophysiological measures has shown that musicians are better at learning the statistical structure of a sung language than non-musicians (François and Schön, 2011, 2014). François and Schön, (2011) reported that musicians had a larger N1 familiarity effect indicating that they could recognize statistically coherent (familiar) items better than unfamiliar items when compared with non-musicians. Additionally, event-related potentials (ERPs) recorded during the familiarization of a sung language showed that the N400 learning curve saturates earlier in musicians than non-musicians, indicating faster detection of statistical regularities in musicians (François and Schön, 2014).

To date, only one study has investigated SL in children learning music (François et al., 2013). François et al. (2013) investigated auditory SL (aSL) using a longitudinal approach in 8-year old children. Twenty-four children were pseudo-randomly divided into two groups in which each group received either music or painting training for a period of two years. Two teachers, specifically trained in music or painting (one for each type of training), were recruited for the study. Each group was trained for 45 min, twice a week in the first year and once a week in the second year. Stimuli used for assessing SL were 4 tri-syllabic 'words' and each word was sung on a particular melodic contour (e.g., the word "pymiso" was sung as B3 E4 F4). Both behavioural and electrophysiological measures were used to assess SL. A two-alternative forced choice (AFC) task was used to assess SL behaviourally. Four part-words were created for the 2 AFC task. Each word (referred to as a familiar word because it was presented during familiarization) was paired with a part-word (referred to as an unfamiliar word because it was not presented during familiarization). While aSL improved over time in children learning music, the performance of the children learning painting remained at chance level on the behavioural measure. In addition, the familiarity effect (difference in ERPs for familiar and unfamiliar words in the 450–550 ms latency range) was larger in the music group than the painting group. The familiarity effect was interpreted as evidence that children learning music could better identify statistical regularities. The authors concluded that the enhancements in aSL may be attributed to better rhythm perception in children with music training. The longitudinal design of this study supports the possibility that music training enhances SL. However, the question of causality remains an open empirical question. It is also possible that children with higher SL may be attracted to musicianship.

To the best of our knowledge, no study has taken an individual differences approach to assess whether higher SL is associated with higher musical abilities such as rhythm or melody discrimination. Furthermore, very little is known about visual statistical learning (vSL) in children with music training, although there are a couple of studies that have shown enhanced visual sequence learning in adult musicians (Romano Bergstrom et al., 2012; Anaya et al., 2017). In the present study, we used a cross-sectional approach to examine the association between SL (both aSL and vSL) and musical training in children.

Behavioural measures of SL are limited by their inability to establish the time course of SL in the brain – they cannot distinguish whether extraction of statistical information was achieved via fast online segmentation or via more slow and variable segmentation processes. To understand the brain dynamics as SL proceeds, we need to measure brain responses like the N1 and the N400 as the stimuli containing regularities are presented during an SL task. These brain responses occur within a few hundred milliseconds of the stimuli being presented (Näätänen and Picton, 1987; Kutas and Federmeier, 2011). This necessitates the use of techniques like electroencephalography (EEG) which are capable of detecting these responses with a suitable temporal resolution such as within milliseconds (Menon et al., 1997). Thus, investigating SL using neurophysiological measures in conjunction with behavioural measures helps us to identify neural correlates of SL. In this study, we used both behavioural and online electrophysiological measures to assess SL.

Previous studies have reported online ERP measures of aSL and vSL in non-musician adults (Abla et al., 2008; Abla and Okanoya, 2009). In these studies, an embedded triplet task was used to assess SL. The embedded triplet task comprised a familiarization and a test phase. During familiarization, a stream of concatenated triplets was presented to the participants. Items within a triplet had a higher chance of co-occurrence or higher transitional probability and were therefore more predictable. Abla and colleagues reported a triplet onset effect (in the N1 and N400 response) as an index for online measure of segmentation during familiarization. The ERPs were larger in less predictable positions (initial stimulus of a triplet) than in more predictable positions (final stimulus of a triplet) which was referred to as a triplet onset effect. Individuals who performed better in the test phase of the SL task showed a larger triplet onset effect.

More recently, our group obtained an online measure of SL using ERPs during aSL and vSL tasks in adult musicians and non-