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Syntactic processing in music and language: Parallel abnormalities observed in congenital amusia

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ABSTRACT

Evidence is accumulating that similar cognitive resources are engaged to process syntactic structure in music and language. Congenital amusia – a neurodevelopmental disorder that primarily affects music perception, including musical syntax – provides a special opportunity to understand the nature of this overlap. Using electroencephalography (EEG), we investigated whether individuals with congenital amusia have parallel deficits in processing language syntax in comparison to control participants. Twelve amusic participants (eight females) and 12 control participants (eight females) were presented melodies in one session, and spoken sentences in another session, both of which had syntactic-congruent and -incongruent stimuli. They were asked to complete a music-related and a language-related task that were irrelevant to the syntactic incongruities. Our results show that amusic participants exhibit impairments in the early stages of both music- and language-syntactic processing. Specifically, we found that two event-related potential (ERP) components – namely Early Right Anterior Negativity (ERAN) and Left Anterior Negativity (LAN), associated with music- and language-syntactic processing respectively, were absent in the amusia group. However, at later processing stages, amusics showed similar brain responses as controls to syntactic incongruities in both music and language. This was reflected in a normal N5 in response to melodies and a normal P600 to spoken sentences. Notably, amusics' parallel music- and language-syntactic impairments were not accompanied by deficits in semantic processing (indexed by normal N400 in response to semantic incongruities). Together, our findings provide further evidence for shared music and language syntactic processing, particularly at early stages of processing.

1. Introduction

In both music and language, discrete elements are combined to form larger structural units according to conventions that can be codified into a set of rules (e.g., rules of tonal structure in music and rules of morphology in language). “Syntax” has been defined broadly as a set of rules governing the combination of discrete structural elements into larger units (Asano and Boeckx, 2015). This broad definition raises the possibility that music and language draw upon shared cognitive resources for syntactic processing (Patel, 2003; see also Koelsch, 2012).

Event-related potential (ERP) studies have shown comparable electrical brain responses during processing music-syntactic and language-syntactic violations in both early and later stages of syntactic processing. At early stages of processing (within a few hundred milliseconds latency), morpho-syntactic mismatches in sentences (e.g., gender disagreement) typically elicit a negative-going deflection with a left-hemispheric preponderance, termed the *Left Anterior Negativity* (LAN; for a review, see Friederici, 2002), which is considered an electrophysiological marker of morpho-syntactic agreement processing (Molinaro et al., 2015). Music-syntactic violations (e.g., out-of-key tones in single melodies and chord violations in harmonised melodies) elicit an early negative-going deflection with a right-hemispheric

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preponderance, termed the *Early Right Anterior Negativity* (ERAN), which is thought to reflect regularity-based music-syntactic processing (for a review, see Koelsch and Friederici, 2003). Koelsch et al. (2005) observed an interaction between the LAN and ERAN components when music- and language-syntactic violations occurred simultaneously. Notably, no such interactions were observed when language manipulations involved semantic incongruities, or when music manipulations involved an unexpected timbre (Koelsch et al., 2005). At later stages of processing, a positive-going deflection – the P600 – is typically elicited by morpho-syntactic violations in language (for a review, see Friederici, 2002). Converging evidence suggests that, the P600 reflects the integration, reanalysis and repair of syntactic information (Friederici, 2002). Patel et al. (1998) has shown that P600 is also elicited by violations of musical key structure and argued that this response is indistinguishable from the one elicited by violations of linguistic syntactic structure in the same participants. Finally, when the music-syntactic violations are task-irrelevant, a negativity called the N5 can be observed which supposedly reflects structure integration and meaning extraction in music (Koelsch, 2011; Koelsch et al., 2000).

Adding to the electrophysiological evidence, behavioural studies also reveal interference between music- and language-syntactic processing. For example, Slevc et al. (2009) found that reading speed for garden-path sentences was slower when combined with structurally unexpected chords than with expected chords (see also Fedorenko et al., 2009; Kunert et al., 2016; Van de Cavey and Hartsuiker, 2016).

In terms of the neural substrates underlying music- and language-syntactic processing, neuroimaging studies have shown overlapping brain regions, such as the bilateral inferior frontal gyrus (e.g., Broca's area; Janata et al., 2002; Koelsch et al., 2002c; Kunert et al., 2015; Maess et al., 2001; Tillmann et al., 2006) and superior temporal gyrus (Koelsch et al., 2002c; Sammler et al., 2013). However, it has been noted that processes associated with the same brain region are not necessarily shared, given the density of neurons within any given area (Peretz et al., 2015).

Disorders in music and language provide another avenue to examine the resource-sharing hypothesis. Music-syntactic deficits have been observed in patients with lesions in “typical language brain areas” (e.g., Patel et al., 2008; Sammler et al., 2011; but such disorders can also arise following damage to other regions, see Peretz, 1993 and Slevc et al., 2016), and in children with developmental language disorders (e.g., Jentschke et al., 2008). Language impairments have also been reported for some individuals with acquired amusia (e.g., Sarkamo et al., 2009). However, it is unclear whether individuals with developmental musical disorders exhibit deficits in both music- and language-syntactic processing.

Congenital amusia is a neurodevelopmental disorder that mainly affects music perception. Unlike typical western listeners, amusic individuals do not favour consonant over dissonant chords (Ayotte et al., 2002; Cousineau et al., 2012), and they have comparatively elevated pitch-discrimination thresholds (Ayotte et al., 2002). They also have difficulty detecting out-of-key notes in melodies in explicit tasks, suggesting reduced sensitivity to musical syntax (Peretz et al., 2002; Peretz et al., 2007). Interestingly, amusic individuals still exhibit implicit knowledge of harmonic syntax (Tillmann et al., 2012) and ERP studies suggest that they may exhibit normal brain responses to mistuned notes at early stages of processing (Mignault Goulet et al., 2012; Moreau et al., 2013; Peretz et al., 2009) but abnormal brain responses, such as an absence of early negativity, when they are asked to respond to music-syntactic mismatches (e.g., out-of-key notes; Peretz et al., 2009; Zendel et al., 2015). These explicit music-syntactic difficulties appear to be independent from their pitch discrimination deficits (Jiang et al., 2016). In other words, individuals with congenital amusia appear to have preserved brain responses to sensory violations, but abnormal brain responses to melodic syntax. Surprisingly, no investigation of congenital amusia has yet examined whether the disorder is associated with parallel deficits in music and language syntactic processing.

If there were shared mechanisms for processing syntax in music and language, then amusic individuals with music-syntactic difficulties should suffer parallel difficulties in language-syntactic processing. To test this hypothesis, we used electroencephalography (EEG) to examine brain responses to syntactic irregularities in music and language among individuals with and without congenital amusia. As a control condition, we also included language semantic irregularity as language-semantic processing is usually believed to operate independently from music-syntactic processing (Carrus et al., 2013; Kunert et al., 2016; Slevc et al., 2009).

To examine music-syntactic processing, ERPs were collected in response to syntactic violations in melodies (i.e., out-of-key notes in tone sequences). We focused on violations of melodic syntax, rather than harmonic syntax, as the latter is the most elementary instantiation of music-syntactic processing, and also because melodic syntax matches the monophonic nature of our language stimuli. A number of studies have confirmed that irregular tones in melodies elicit frontal potentials that can be interpreted as the ERAN response to music-syntactic violations (Besson and Faita, 1995; Besson and Macar, 1987; Koelsch and Jentschke, 2010; Miranda and Ullman, 2007; Paller et al., 1992). Moreover, when melodic and harmonic syntactic violations are compared directly, both elicit ERAN responses, but harmonic violations elicit additional responses that are not observed with melodic stimuli, reflecting emergent qualities that arise when individual melodic voices are combined to form a harmonic sequence (Koelsch and Jentschke, 2010). This comparison illustrates that brain responses to harmonic sequences cannot be entirely predicted from responses to the melodies that make up those harmonic sequences, corroborating earlier perceptual findings involving the same comparison (Thompson, 1993; Thompson and Cuddy, 1989, 1992).

Unlike syntactic irregularities in language, which concern violations of expectations about the function and order of words, syntactic irregularities in melody fundamentally entail unexpected acoustic information, which has the potential to complicate the interpretation of brain responses to such irregularities (Bigand et al., 2006). However, brain responses to sensory violations are evoked by an unexpected change to a sequence of elements containing a constant sensory attribute, such as pitch or loudness (Peter et al., 2010). In contrast, syntactic violations in melody do not require pitch (or other sensory attributes) to be held constant in a sequence, because syntax operates at a more abstract level that is determined by the implied tonal hierarchy.

In this investigation, we re-examined whether individuals with congenital amusia exhibit typical brain responses to violations of melodic syntax, while also investigating whether they exhibit typical brain responses to language-syntactic irregularities. We hypothesised that, in comparison to the control group, amusic individuals would exhibit abnormal brain responses to both music-syntactic violations and language-syntactic irregularities if processing music and language syntax involves shared cognitive mechanisms. However, we expected that amusic and control groups would exhibit normal brain responses to non-syntactic unexpected events in music and language.

2. Materials and methods

2.1. Assessment of congenital amusia

In the present study, amusic participants were identified using a screening method based on the three pitch-related subtests (Scale, Contour and Interval) from the Montreal Battery of Evaluation of Amusia (MBEA; Peretz et al., 2003) with an aggregate accuracy rate of 72.22% being the cutoff (i.e., 65 out of 90 points; Liu et al., 2010; Sun et al., 2017; Thompson et al., 2012). The ability to detect changes in melodic pitch, assessed by the three subtests that we employed, is fundamental to the processing melodic syntax, which was the focus of our investigation. Given that the cutoff based on the percentage of correct responses is subject to response bias, which may lead to

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