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Music and words in the visual cortex: The impact of musical expertise

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ABSTRACT

How does the human visual system accommodate expertise for two simultaneously acquired symbolic systems? We used fMRI to compare activations induced in the visual cortex by musical notation, written words and other classes of objects, in professional musicians and in musically naïve controls. First, irrespective of expertise, selective activations for music were posterior and lateral to activations for words in the left occipitotemporal cortex. This indicates that symbols characterized by different visual features engage distinct cortical areas. Second, musical expertise increased the volume of activations for music and led to an anterolateral displacement of word-related activations. In musicians, there was also a dramatic increase of the brain-scale networks connected to the music-selective visual areas. Those findings reveal that acquiring a double visual expertise involves an expansion of category-selective areas, the development of novel long-distance functional connectivity, and possibly some competition between categories for the colonization of cortical space.

1. Introduction

A substantial part of individual differences in cognitive abilities results from the individual practice of highly trained skills. The brain correlates of such acquired expertise have been accessible to anatomical and functional brain imaging for over two decades, in a broad variety of domains ranging from navigation in space (Maguire et al., 2000), juggling

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(Gerber et al., 2014), to olfactory (Delon-Martin, Plailly, Fonlupt, Veyrac, & Royet, 2013) and visual (Gauthier, Skudlarski, Gore, & Anderson, 2000; Harel, Kravitz, & Baker, 2013) expertise. Word reading may be the culturally most important and widely shared expertise, entailing both anatomical and functional differences between the brain of literate and illiterate individuals (Carreiras et al., 2009; Dehaene et al., 2010; Thiebaut de Schotten, Cohen, Amemiya, Braga, & Dehaene, 2014). Learning to read yields functional changes in the visual cortex, including the development of a word-selective area in the left occipitotemporal region (Cohen et al., 2000), and the displacement of the neighboring face-selective area toward the right hemisphere (Dehaene et al., 2010). The acquisition of expertise thus entails both the emergence of novel local specialization and a competition between classes of stimuli. How then does the visual system accommodate expertise for several independent symbolic systems, as occurs for instance in high-level musicians who simultaneously acquire alphabetic and musical notations? Category-selectivity is a dominant organizing feature of the ventral visual cortex (Grill-Spector & Weiner, 2014), and it could be expected that distinct occipitotemporal regions may be devoted to different symbolic systems. The preferences of a given cortical patch for a given type of visual objects may result from two causes (Hannagan, Amedi, Cohen, Dehaene-Lambertz, & Dehaene, 2015). First, *a priori* perceptual biases, e.g., preference for foveal versus peripheral stimuli (Hasson, Levy, Behrmann, Hendler, & Malach, 2002), make each cortical site more or less suitable to represent different types of stimuli (Srihasam, Vincent, & Livingstone, 2014). Second, preferences may also arise from privileged connections with distant regions involved in domain-specific functions (Mahon & Caramazza, 2009; Plaut & Behrmann, 2011; Saygin et al., 2012).

Both factors may contribute to the reproducible placement of the reading-selective Visual Word Form Area (VWFA, Cohen et al., 2000). First, it falls in a cortical region with a preference for foveal over peripheral stimuli (Hasson et al., 2002), for analytical over configural processing (Ventura et al., 2013), and for sensitivity to line junctions (Szwed et al., 2011). Second, the VWFA also shows stronger anatomical connectivity with perisylvian language areas compared to the neighboring Fusiform Face Area (FFA) (Bouhali et al., 2014).

Alphabetic and musical notations make use of substantially different visual features, and the two sets of symbols are used to trigger different cognitive abilities. Therefore, both perceptual biases and long-distance connectivity would predict segregated cortical preferences for the two domains.

Paradoxically, strong empirical support for the cortical segregation of different symbolic systems comes from a recent study in monkeys. Macaques were trained at identifying alphabetic symbols, Tetris-like shapes, and sketchy cartoon faces. Following training, monkeys developed distinct regions selective for each of the three sets, at reproducible locations within the occipitotemporal cortex (Srihasam, Mandeville, Morocz, Sullivan, & Livingstone, 2012, 2014). In humans, there is also evidence for segregated activations for letters and numerals in the fusiform gyrus (Abboud, Maidenbaum, Dehaene, & Amedi, 2015; Polk et al., 2002; Shum et al., 2013), and for Chinese versus alphabetic stimuli in the early visual cortex (Szwed, Qiao, Jobert, Dehaene, & Cohen, 2014). There are also some indications of segregated activations for printed words and musical notation in the occipitotemporal cortex (Wong & Gauthier, 2010a), but this evidence is controversial (Muayqil, Davies-Thompson, & Barton, 2015) and is not supported by statistical comparisons of activation topography between words and music.

Here, in order to study the cortical segregation of symbolic systems, we used fMRI to assess activations induced by musical notation in the left occipitotemporal cortex, in professional musicians and naive controls, comparing them to activations by written words and other classes of objects (Fig. 1). From the above considerations we derived four core predictions, which we assessed using novel individual analyses of activation topography and volume. First, music notation differs from words both in terms of visual features and of associated representations, semantic and other. Therefore we expected to find music-selective activations topographically distinct from other category-selective regions in the ventral stream. Second, visual encoding of music scores differs between musicians and naïve subjects (Stewart, 2005). Hence we predicted that music-related activations should differ depending on musical expertise. Such differences might affect the location, the amplitude, or the spatial expansion of music-related activations. Third, we predicted that musical expertise could interact with other categories, particularly words, affecting the location, the amplitude, or the volume of nearby word-related activations. Fourth, if indeed we identify distinct visual regions selective for words and music, the functional connections of the music-selective area to the rest of the brain should differ depending on musical expertise, while the connections of the word-selective area should not differ across groups.

2. Materials and methods

2.1. *Subjects*

Twenty-four musicians and 24 control subjects gave written informed consent to participate in the study. Three musicians were excluded because of technical defects or claustrophobia during fMRI acquisition; one control was excluded because after scanning he admitted to some musical competence. The two groups were matched for age (mean age: controls 29.8 years, SD = 10; musicians 32.6 years, SD = 10), gender (controls: 13 men; musicians: 12 men), and educational level (schooling: controls 14.7 years, SD = 1.8; musicians 15.7 years, SD = 1.8). All were right-handed according to the Edinburgh inventory (Oldfield, 1971) and had normal or corrected-to-normal vision. Three musicians, although perfectly fluent French speakers, were not native French speakers. Musicians were either Master students at the CNSM (Conservatoire National Supérieur de Musique et de Danse de Paris), or professional musicians. Their main instrument was the cello ($n = 3$), the violin ($n = 6$), the trumpet ($n = 1$), the oboe ($n = 3$), the recorder ($n = 1$), the viola ($n = 1$), the piano ($n = 6$), the harpsichord ($n = 1$), and the clarinet ($n = 1$). Two participants were equally proficient with two instruments. Professional musicians were concert performers, music teachers, orchestra and