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Tracking changes in spatial frequency sensitivity during natural image processing in school age: an event-related potential study

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ABSTRACT

Several studies have shown that behavioral and electrophysiological correlates of processing visual images containing low or high spatial frequency (LSF or HSF) information undergo development after early childhood. However, the maturation of spatial frequency sensitivity during school age has been investigated using abstract stimuli only. The aim of the current study was to assess how LSF and HSF features affect the processing of everyday photographs at the behavioral and electrophysiological levels in children aged 7–15 years and adults. We presented grayscale images containing either animals or vehicles and their luminance-matched modified versions filtered at low or high spatial frequencies. Modulations of classification accuracy, reaction time, and visual event-related potentials (posterior P1 and N1 components) were compared across five developmental groups and three image types. We found disproportionately worse response accuracies for LSF stimuli relative to HSF images in children aged 7 or 8 years, an effect that was accompanied by smaller LSF-evoked P1 amplitudes

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during this age period. At 7 or 8 years of age, P1 and N1 amplitudes were modulated by HSF and LSF stimuli (P1: HSF > LSF; N1: LSF > HSF), with a gradual shift toward the opposite pattern (P1: LSF > HSF; N1: HSF > LSF) with increasing age. Our results indicate that early cortical processing of both spatial frequency ranges undergo substantial development during school age, with a relative delay of LSF analysis, and underline the utility of our paradigm in tracking the maturation of LSF versus HSF sensitivity in this age group.

Introduction

When we look at a complex visual scene such as a street containing living beings and artificial objects, our visual system analyzes the image at different spatial scales simultaneously (Campbell & Robson, 1968). On a subcortical level, low and high spatial frequencies (LSF and HSF) are coded by the magnocellular (M) and parvocellular (P) subcortical channels, respectively (Livingstone & Hubel, 1988). Whereas global characteristics of the visual input such as image layout and object shapes are primarily determined by LSF information and activity in the M system, HSF-sensitive P neurons convey information about local stimulus details and fine texture (Livingstone & Hubel, 1988; Schiller, Logothetis, & Charles, 1990). Not only does functioning of these two channels determine visual processing in adults, but due to their unique developmental patterns across infancy and childhood, the channels also shape how children perceive the world (Atkinson, 1992; Johnson, 2005; Leonard, Karmiloff-Smith, & Johnson, 2010).

Visual perception during the first months of life is dominated by coarse LSF information (Adams & Courage, 2002; Braddick & Atkinson, 2011; Gwiazda, Bauer, Thorn, & Held, 1997; Hammarrenger et al., 2003). In this period infants perceive relatively few details, but this ability develops rapidly in the first years of life (Adams & Courage, 2002; Gwiazda et al., 1997). There is ample evidence that the maturation of both LSF and HSF processing continues after infancy, but at a different speed. Several behavioral studies using abstract stimuli such as sinusoidal luminance-contrast gratings found that development of LSF sensitivity lags behind that of HSF between 8 and 12 years of age (Adams & Courage, 2002; Benedek, Benedek, Kéri, & Janáky, 2003; Benedek et al., 2010; Gwiazda et al., 1997). However, there is also evidence for the ongoing development of HSF processing at 12 years because children's performance is still not adult-like at this age (van den Boomen & Peters, 2017). Finally, a study assessing the maturation patterns of HSF versus LSF sensitivity using two spatial frequencies reported similar trajectories for both stimulus types between 5 years of age and early adulthood (Patel, Maurer, & Lewis, 2010). Thus, it seems that both LSF and HSF processing are characterized by prolonged but nonlinear maturation, and currently it is difficult to know whether either LSF or HSF analysis is fully mature before adulthood because this might depend on the spatial frequency (SF) range tested and the stimulus contrasts and/or paradigms used. It is important to note, however, that none of the above studies used complex meaningful stimuli, such as photographs of everyday objects or scenes, or applied a task that required participants to recognize and discriminate stimuli based on their semantic content. Studying the development of SF processing with paradigms sensitive to higher-level vision can have important implications not only for typical development but also for certain neurodevelopmental disorders that are simultaneously characterized by altered SF sensitivity and disrupted processing of complex stimuli (Deruelle, Rondan, Gepner, & Tardif, 2004; Gori, Seitz, Ronconi, Franceschini, & Facoetti, 2016; Vlamings, Jonkman, van Daalen, van der Gaag, & Kemner, 2010). This is because processes linked to more elaborate visual analysis, such as the detection of category-specific features, might not be recruited to the same degree in experiments using relatively simple designs; hence, the influence of disrupted SF sensitivity on vision in, for example, autism spectrum disorder or developmental dyslexia might be different for sinusoidal luminance-contrast gratings relative to emotional facial expressions or written words, respectively.