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Integrity of lateral and feedbackward connections in visual processing in children with pervasive developmental disorder

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Abstract

Enhanced visual detail processing in subjects with pervasive developmental disorder (PDD) has been related to impairments in feature integration. The functional integrity of two types of neuronal connections involved in visual feature integration, namely horizontal and feedbackward connections, were tested.

Sixteen children with PDD and 17 age- and IQ-matched control children (mean age 13.3 years) were included. In a texture segregation task the difference in ERP response to homogeneous and checkered visual stimuli was determined. Additionally, in a contour integration task subjects had to point out a contour consisting of colinearly aligned Gabor signals in backgrounds increasing in noise.

Children with PDD showed a normal performance on the contour integration task, suggesting that neurons in the primary visual cortex of children with PDD can effectively integrate the activity of local detectors that process different aspects of the same object information by making use of long-range lateral connections. The amplitude of ERP activity related to texture segregation was also not different between the PDD and control groups, indicating functional visual feedback mechanisms between V1 and higher order areas in subjects with PDD. However, a difference in latency of texture-segmentation related activity between the groups was noted. This effect did not reach significance, which could be due to the small N of the study. Therefore, the data need replication in a study with larger samples before more definitive conclusions can be drawn.

Keywords: Pervasive developmental disorders; Autistic disorder; Event-related potentials; Visual integration

1. Introduction

Although impairments in the social domain are the best known characteristics of PDD, there is an increasing realization that subjects with PDD show atypical processing that is not restricted to socially relevant stimuli. More specifically, subjects with PDD are usually found to excel in visuo-spatial tasks that require detail processing and neglect of the relationship between details, such as the block design test and Embedded Figures Test (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1993). There are indications that extensive detail processing also plays a role in abnormal behavior of autistic subjects in the social domain, such as abnormal face processing (Klin et al., 1999; Schultz et al., 2000). It has been suggested that these findings point to abnormal integration of visual features in subjects with PDD, resulting in an impaired ability to perceive aspects of global stimuli, and this was conceptualized as 'weak central coherence' (Frith, 1989). Indeed, several functional studies have been published that provide evidence for impaired integration of information at a large-scale level, i.e. between relatively distant (sub) cortical areas (Castelli, Frith, Happe, & Frith, 2002; Schultz et al., 2000). Additionally, abnormalities in white matter tracts indicate abnormal structural connectivity between cortical areas in subjects with PDD (Barnea-Goraly et al., 2004). However, there is little knowledge on the anatomical base for abnormal visual feature integration in PDD, which relies on processing on a more small-scale level, i.e. within the visual cortex.

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The integration of visual features in healthy subjects is usually explained in the context of the feedforward model of visual processing. This model builds on the anatomical hierarchy of cortical areas: the neurons of low-level areas represent simple features, which are integrated and transferred via feedforward corticocortical connections toward higher levels of stimulus integration. While the primary cortex is involved in the analysis of elements, the integration of these elements is thought to occur in the temporal and parietal cortices. According to this model, PDD would be associated with an abnormality in feedforward integration systems. However, the feedforward view of visual perception is now being challenged. Feedforward connections are reciprocated by numerous feedback fibers, and there is increasing evidence that these feedback-connections are effective in integrating information. For example, in a recent model of visual processing, reverse hierarchy theory (RHT), feedforward and feedbackward processing are directly associated with the perception of global and local aspects of a stimulus, respectively. According to RHT, feedforward processing occurs first, resulting in a representation of the global aspects of a scene at higher cortical levels. Later recurrent processing to lower areas provides detailed information (Hochstein & Ahissar, 2002). There are indications that in PDD the primary abnormality is not in the processing of global percepts. Several studies have shown that individuals with PDD can respond to the global level of a hierarchical stimulus in the same way as controls, but sometimes respond better to the local level of a stimulus (Mottron, Burack, Iarocci, Belleville, & Enns, 2003; Ozonoff, Strayer, McMahon, & Filloux, 1994; Plaisted, Swettenham, & Reese, 1999). Individuals with PDD also perform visual search tasks better (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998), and these findings have led to the suggestion that subjects with PDD have a greater awareness of individual features of a stimulus (Mottron & Burack, 2001) Since perceptual awareness of stimulus details is associated with feedbackward activity, an alternative explanation for increased detail processing in PDD is that feedbackward activity is relatively stronger in this group. Abnormal structural cortical connections between several brain areas have been reported in subjects with PDD (Barnea-Goraly et al., 2004). If such deficient wiring would occur between occipital areas in subjects with PDD, this is likely to affect the delicate interaction between visual feedforward and feedbackward processing.

Another important mechanism for visual integration are the horizontal neuronal connections within the visual cortex. Studies have shown the existence of extensive axonal collaterals of pyramidal cells in layers 2 and 3 of the primary visual cortex, which may span several millimeters horizontally across the cortex. It is assumed that these neuronal connections are involved in the integration of the activity beyond the neuron's receptive field (Kovács & Julesz, 1993; Lamme & Roelfsema, 2000). Recent neuropathological studies demonstrate that subjects with autism have more numerous and more narrow minicolumns than control subjects (Casanova, Buxhoeveden, Switala, & Roy, 2002a; Casanova, Buxhoeveden, Switala, & Roy, 2002b) providing a neuroanatomical base for integration abnormalities within cortical areas.

So, both feedback and horizontal connections are involved in normal visual feature integration. There is increasing attention for the role of such low-level mechanisms in atypical visuo-spatial processing in PDD (Dakin & Frith, 2005). More specifically, two recent studies have related deficient processing in specific visuo-spatial tasks with abnormalities in neurointegrative mechanisms in the visual cortex (Bertone, Mottron, Jelenic, & Faubert, 2003; Bertone, Mottron, Jelenic, & Faubert, 2005). Using first- and second order static stimuli, superior processing of first order stimuli, but decreased processing of second-order stimuli was shown in subjects with PDD. The authors suggested that feedback connections between V1 and higher order visual areas (V2/V3) are necessary for the processing of second order stimuli. The processing of first order stimuli, on the contrary, would rely on V1 only (Bertone et al., 2005). Therefore, the impaired processing of second-order stimuli was interpreted as an indication for abnormal integration of information between brain regions. However, this study was not aimed to test the functional integrity of visual structures involved in feature integration, and provides only indirect evidence for abnormalities in this respect in PDD.

The present study is aimed to test as direct as possible the functioning of lateral and feedbackward connections in school age children with PDD by means of a contour integration and a texture segmentation task. In both tasks, lateral as well as feedforward/feedbackward connections are probably important. However, the design of the tasks allows focusing specifically on, respectively, lateral and feedbackward connections. The contour-integration task consists of cards including a closed chain of collinearly aligned Gabor signals (contour), which the subjects have to point out, and a background of randomly oriented and positioned Gabor signals (noise). The cards increase in amount of noise, and at low signal to noise ratios, the subject is forced to rely on horizontal connections in primary visual cortex in integrating the orientation of the Gabor elements, and finding the contour (Kovács, Polat, Norcia, Pennefather, & Chandna, 2000). The second task is aimed to study texture segregation, a prerequisite for the segregation of scenes into objects and background. It involves the pre-attentive processing of certain visual dimensions, such as luminance, color, orientation, or direction of motion, identifying differences between adjoining regions in the visual field. Texture segregation can be studied by presenting visual stimuli containing the same feature presented in two ways, such as lines in different orientations (like the checkerboards used in the present study), and comparing the event-related potentials evoked by these stimuli to the potentials evoked by presentation of the same feature presented in a homogeneous fashion (i.e. lines solely in a horizontal direction or solely vertical). Electrocortical activity in response to textured stimuli is enhanced compared to the activity evoked by homogeneous stimuli at latencies ranging from 100 to 250 ms after stimulus onset (Bach & Meigen, 1997; Fahle, Quenzer, Braun, & Spang, 2003; Lamme, Van Dijk, & Spekreijse, 1992). This EEG activity is directly related to similar modulations of activity that can be recorded in V1 of the awake monkey, and that have been shown to depend on recurrent neural interactions between V1 and higher visual areas; removal of the extra-striate areas abolishes the