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ERPs and Eye Movements Reflect Atypical Visual Perception in Pervasive Developmental Disorder

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Many studies of eye tracking or event-related brain potentials (ERPs) in subjects with Pervasive Developmental Disorder (PDD) have yielded inconsistent results on attentional processing. However, recent studies have indicated that there are specific abnormalities in early processing that are probably related to perception. ERP amplitudes in response to visual stimuli, measured above the occipital (modality-specific) cortex, are reported to be abnormally small in patients with PDD, and the abnormal visual processing is possibly associated with the spatial visual frequency content of stimuli. It is suggested that subjects with PDD show abnormal activation of visual pathways dedicated to the processing of high and low spatial frequencies.

KEY WORDS: Event-related potential; P300; eye movement; perception.

Perception is a broad concept, but usually refers to the translation of sensory stimulation into organized experience. In this definition, perception refers mainly to the stimulus processing that occurs in modality-specific brain areas in the first few hundred milliseconds after stimulus presentation. Recent studies have shown the existence of early feedback loops from higher-order processing areas to areas traditionally related to perceptual processing, which suggests that perceptual and higher-order processes might be more intertwined than previously thought (e.g. Lamme, 2003). However, in this review we refer to perceptual processing as the activation of modality-specific brain areas relatively early after stimulus presentation.

Event-related brain potentials (ERPs) can be used to study perceptual processing in subjects with Pervasive Developmental Disorder (PDD), since they provide information about the timing of neural events and, to a limited extent, about the localization of these processes. ERPs reflect the electrical brain activity that occurs after the presentation of a stimulus and are usually measured for about 1 second after stimulus presentation by electrodes attached to the scalp. ERPs have a wave-like appearance, and the different peaks and troughs, which are mostly referred to in terms of their polarity and occurrence in time, reflect specific aspects of processing. In this review, the amplitude of an ERP peak is considered to reflect the amount of processing invested in a stimulus, and its latency provides information about the timing of a specific processing stage.

Another source of information on perceptual processes in individuals with PDD is eye gaze, since brain activation is related to the way a stimulus is looked at, for instance, whether a stimulus is in the

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fovea of the eye. Studies of eye gaze usually use infrared techniques to measure the position of the eye in relation to stimuli presented on a television screen. This review includes ERP and eye movement studies on visual processing in PDD. The studies discussed focus either on attentional processing or on the functioning of the dorsal and ventral visual pathway in PDD. Studies of the former are usually older, and experimental and control groups are often not well matched (especially on IQ), whereas studies on the latter are more recent and fulfill current criteria on subject matching better.

Most early visual ERP studies in PDD have focused on tasks testing the functioning of visual attention systems, and especially the processing of deviant or novel stimuli. These studies were inspired by the observation that subjects with PDD react abnormally to changes in the environment, which suggests that orienting is defective in these individuals. The typical paradigm used in these studies is the oddball task. In an oddball experiment, two classes of stimuli are presented, a frequently occurring standard, and an infrequently occurring deviant. In another type of oddball task, three classes of stimuli are presented, including standards, deviants, and a series of unique, unexpected deviant stimuli, the novels. Oddball tasks may be presented in active or passive mode. In the active mode, the subject is required to attend to the deviant stimuli and to respond to these by pressing a button. In the passive mode, the subject is not actively engaged with the stimuli. Another type of task related to attentional processing is the selective attention task. Selective attention tasks are in fact oddball tasks that involve two channels of stimulation (e.g. for visual attention tasks, stimuli could presented in two different colors or locations). These tasks are primarily aimed to investigate the ability to focus on a specific source of information.

In oddball tasks the main ERP peak of interest is the P3 or P300, a positive deflection peaking at about 300 ms in adults and usually later in children, which is maximal at parietal sites. The P3 amplitude is sensitive to both stimulus probability and attention to a stimulus (task instruction), and increases in amplitude in response to deviant and/or task-relevant stimuli. In most studies of PDD, it is the main peak of interest in response to deviant stimuli. Late frontal negativity, referred to as either Nc or N400, is often recorded during the performance of tasks involving novel stimuli. In selective attention tasks, negativity with a fronto-central distribution is increased in response to attended stimuli; this activity is often termed Processing Negativity (PN). It is not known which sources are involved in the generation of these ERP peaks. The P3 is suggested to have multiple generators originating in several brain areas, such as temporal and frontal areas (Herrmann & Knight, 2001). Likewise, given the scalp distribution of the Nc and PN, with a clearly frontal maximum, at least some of the activity is likely to originate from frontal, modality aspecific, generators (e.g. Jonkman, Kenemans, Kemner, Verbaten, & van Engeland 2004). Earlier peaks, around 100 msec, can also be detected and are usually associated with activity in the modality specific cortex, namely the N80 and the P1 (Herrmann & Knight, 2001).

Recognition of the fact that visual processing occurs in two major functionally and anatomically segregated pathways, i.e. the ventral and dorsal pathways (e.g. Ungerleider & Haxby, 1994), has influenced the scope of visual ERP studies. The ventral pathway is associated with the processing of details; the dorsal pathway with the processing of movement and global information. Results suggesting that subjects with PDD excel on tasks that require attention to detail, such as the block design task and the embedded figures test (e.g. Ropar & Mitchell, 2001; Shah & Frith, 1983), have prompted studies on the functioning of these pathways. So far, two types of ERP and eye gaze studies on this topic have emerged. First, ERP studies on spatial frequency processing, that capitalize on the fact that the dorsal and ventral pathway differ in sensitivity to high and low spatial frequencies. Low visual spatial frequencies are thought to be associated with the perception of diffuse aspects of an image and to be mainly processed in the dorsal stream, and high visual spatial frequencies are associated with detailed aspects of an image and ventral stream processing (e.g. Hughes, Nozawa, & Kitterle, 1996; Schiller & Logothetis 1990). Second are studies involving face processing, since data suggest that subjects with PDD also show face processing strategies based on detail (e.g. Schultz *et al.*, 2000), and that the dorsal and ventral pathways are differentially involved in the processing of faces. Static face information, which is important in the recognition of identity, is processed via the ventral pathway, whereas dynamic face information, such as eye, mouth and face movements, head orientation, and emotional expression, is processed in the dorsal pathway (see Haxby, Hoffman, & Gobbini, 2000). Additionally, a topic in several studies on face processing in PDD is processing mode. In normal subjects, face processing is thought to rely on holistic information. Inversion of the face results in detail-based processing strategies, analogous to strategies involved in the processing of objects. In contrast, subjects with PDD are thought to rely on detail processing strategies, not only for objects and inverted faces but for normally oriented faces as well. Recently, a negative ERP peak was identified that shows a maximal response to face stimuli. This so-called N170 peak occurs over temporo-parietal regions at about 170 ms and is also sensitive to processing mode. The N170 is larger and often occurs earlier in response to upright faces than in response to inverted faces or other visual object categories and has therefore been related to holistic processing. The N170 is thought to reflect activity from the visual ventral pathway (Allison, Puce, Spencer, & McCarthy, 1999; Bentin, Allison, Puce, Perez, & McCarthy, 1996).

ERP AND EYE MOVEMENT STUDIES OF ATTENTION IN PDD.

Orienting to Deviancy and Novelty

Several oddball studies have indicated that subjects with PDD show an increase in P3 amplitude in response to targets, as compared to standard stimuli, comparable to the effects usually found in healthy subjects (Courchesne, Lincoln, Kilman, & Galambos, 1985; Pritchard, Raz, & August, 1987; Verbaten, Roelofs, Van Engeland, Kenemans, & Slangen, 1991). However, smaller increases in P3 amplitude in response to targets in PDD groups have also been reported (Ciesielski, Courchesne, & Elmasian, 1990; Courchesne, Lincoln, Yeung-Courchesne, Elmasian, & Grillon, 1989). It should be noted that in none of these oddball studies control and clinical subjects were matched for age and/or IQ—PDD subjects usually had a considerably lower IQ than control subjects. In addition, an abnormally small Nc was noted in subjects with PDD in response to novel stimuli (Verbaten *et al.*, 1991) and target stimuli (Courchesne *et al.*, 1985; Courchesne *et al.*, 1989), although in another study subjects with PDD showed normal late frontal negativity in response to visual novels (Kemner, Verbaten, Cuperus, Camfferman, & Van Engeland, 1994). These data do not indicate a consistent abnormality in orientation to deviant or novel stimuli in subjects with PDD, as reflected by either P3 or Nc.

Issues on Processing Capacity

The finding that the P3 amplitude is smaller in subjects with PDD has prompted the question whether this could be due to limited resources of the neuronal system that generates the P3. Results suggest that the P3 amplitude during performance of a task is associated with the processing capacity needed for the task (Kok, 1997). Hoeksma and colleagues used a probe task to measure processing capacity in high-functioning children and adolescents with PDD and age- and IQ-matched control groups. In this task, visual probe stimuli were presented during an auditory task with two levels of difficulty. The authors hypothesized that the extra resources needed for the processing of auditory stimuli in the difficult task would to be ‘borrowed’ from the capacity needed for the processing of the visual stimuli, and that this would be reflected by a decrease in visual P3 amplitude. Indeed, a trade-off effect was found in the normal controls: the P3 amplitude was smaller for the difficult task than for the easy task. However, this difference in P3 amplitude according to task difficulty was not seen in children or adolescents with PDD, suggesting that subjects with PDD do not suffer from a shortage of processing capacity, but rather from a deficient allocation thereof (Hoeksma, Kemner, Verbaten, & van Engeland, 2004).

It is generally assumed that complex stimuli require more processing capacity than simple stimuli, and it has been suggested that autistic subjects have a specific problem with the processing of complex information (e.g. Minshew, Sweeney, & Luna, 2002). It should be noted, however, that the term stimulus complexity is quite vague and is usually not defined (except in a study by Verbaten *et al.*, 1991). Complexity can either refer to stimulus parameters, such as the number of elements the stimulus consists of, to the hierarchical level of the brain region that is most sensitive to the stimulus, or to the number of mental operations needed to process the stimulus. For example, one could argue that schematic face stimuli are less complex than photographs of faces, since they contain fewer elements or details. Also, simple geometric figures could be argued to be less complex than schematic faces, since they are processed earlier in visual hierarchy. Likewise, dynamic face stimuli are probably more complex than static face stimuli, since they include movement, and therefore require not only ventral processing but also dorsal processing. However, it is difficult to determine how these definitions of complexity interrelate.

Stimulus complexity was manipulated in two studies involving subjects with PDD. A study in which a difference between autistic and control subjects was found with respect to the P3 amplitude in response to highly complex stimuli is difficult to interpret because the subjects were not matched for IQ (Verbaten *et al.*, 1991). A study comparing the looking behavior of high-functioning school-age children with PDD and age- and IQ-matched control children during the presentation of simple or complex schematic visual objects and faces did not detect differences in fixation time or number of fixations for either simple or complex stimuli between the two groups of children (Kemner, van der Geest, Varbaten, & van England, submitted). These results do not support the notion that there are abnormalities of complexity processing in PDD, although abnormalities have been reported in behavioral studies (Minshew *et al.*, 2002). However, it should be noted that the complexity manipulations in the ERP studies were limited to the first concept of complexity, namely the number of elements a stimulus contains. It is possible that manipulation of other aspects of complexity might reveal processing abnormalities in subjects with PDD.

Abnormal Early Processing: Selective Attention?

An alternative explanation for abnormal P3 amplitudes in subjects with PDD is that they are the result of an abnormality in a processing stage before the P3, especially in the ability to focus attention on stimuli. No oddball studies have reported abnormalities in ERP peaks related to attentional processing preceding the P3, but it may well be that oddball manipulations are not sensitive enough to detect such abnormalities. A potential earlier candidate for atypical processing is the ability to direct attention to a specific source of information, such as the color or the position of stimuli, i.e. the ability for selective attention. A few studies have investigated ERPs in subjects with PDD during the performance of selective attention tasks. In one study a combined visual and auditory task was used, in which the subjects had to attend to the visual stimuli and to ignore the auditory stimuli, or vice versa. In the condition in which the subjects had to pay attention to the visual stimuli, ERP-selective attention effects were found in the control group but not in a group of children with PDD (Ciesielski *et al.*, 1990). However, these group differences were not found in a later study using the same task (Ciesielski, Knight, Prince, Harris, & Handmaker 1995). Moreover, in neither study were subjects matched for age or IQ (the control subjects had a higher IQ than the autistic subjects).

Visual selective attention was also studied, using a unimodal task, in two different age groups of subjects with PDD, who were matched for age and IQ with normal control groups. There were no differences between the clinical and control group in selective attention-associated ERP peaks in the youngest age group (school-age children). The ERP data of the adolescent subjects with PDD, however, indicated an increased selective attention in this group (Hoeksma, Kemner, Kenemens, & van England, in press). In a study of spatial selective attention in adult subjects with PDD, age but not IQ matched with a group of normal controls, it was found that activity associated with the orienting of attention to a specific point in space was delayed in autistic subjects, but only under conditions in which attention was oriented to peripheral visual fields (Townsend *et al.*, 2001). Again, these studies show no unambiguous indications for atypical attentional focusing.

With respect to eye movement studies related to attention in PDD, one study reported that children with PDD made more saccadic eye movements, which could reflect an increase in attentional shifts (Kemner, Verbaten, Cuperus, Camfferman, & van Engeland, 1998). To study attention shifting more directly, saccadic eye movements were measured during a so-called gap-overlap task. In this task, subjects are required to make a saccadic eye movement from a fixation point to a target stimulus, as quickly as possible after presentation of the target. There are two conditions: the gap condition, in which the fixation point disappears before the presentation of the target stimulus, and the overlap condition, in which a fixation point remains visible at the moment of target presentation. The saccadic latency is usually smaller in the gap condition than in the overlap condition. This so-called gap effect can been explained by assuming that visual attention is already disengaged during target presentation in the gap condition, so that the subject can shift attention, as measured by saccadic latency, rapidly. However, in the overlap condition, visual attention is still focused on a location and has to be disengaged before a new target location can be selected, resulting in longer saccadic reaction times (Fisher & Weber, 1993). In two studies both control children and children with PDD showed shorter saccadic reaction times in the gap condition than in the overlap condition. There were no significant differences in saccadic reaction times between the two groups of children (Kawakubo, Maekawa, Itoh, Hashimoto, & Iwanami, 2004; Van der Geest, Kemner, Camfferman, Verbaten, & van Engeland, 2001). One study reported a smaller gap effect in autistic children than in normal control children (Van der Geest *et al.*, 2001), which implies that the ability of autistic children to shift attention is influenced less than in control children by the current state of visual attention, but there is no evidence that children with autism are less able to shift their attention.

Abnormal Activity Above the Occipital Cortex

Several studies have reported atypical activity in the visual cortex in subjects with PDD. In a study of visual selective attention, the amplitudes of both the P1 and P3 peaks measured at the Oz electrode were smaller in response to all stimuli investigated, indicating decreased activity of the modality-specific cortex both in early and late phases of processing in children with PDD (but not in adolescent subjects with PDD) (Hoeksma *et al.*, in press). Likewise, in a visual oddball study, the amplitude of the occipital P3 was smaller in children with PDD, especially in response to non-task relevant stimuli (Kemner *et al.*, 1994). Smaller P1 amplitudes in PDD children were also found in response to grating stimuli (Boeschoten, Kemner, Kenemans, & van Engeland, submitted). These data indicate that perceptual visual processing is abnormal in PDD. More recent ERP studies have focused more specifically on aspects of visual perception in PDD. The two main topics investigated so far are face processing and the processing of visual spatial frequencies (see below).

STUDIES ON DORSAL AND VENTRAL STREAM FUNCTIONING.

Spatial Frequency Processing

Indications that subjects with PDD show atypical processing of visual spatial frequencies were found in an ERP study in which gratings of both low and high spatial frequencies were presented to high-functioning school age children with PDD and age- and IQ-matched normally developing controls (Boeschoten *et al.*, submitted). The N80 peaks in response to gratings of high spatial frequencies had a smaller amplitude in children with PDD than in developmentally normal children. The N80 in response to low spatial frequency gratings was the same in both groups. Analysis of the sources of the N80 activity showed that the source configuration for the low spatial frequencies was similar in control and PDD children, whereas the source configuration for high spatial frequencies was different. In the control children a more posteriorly located source was activated during the processing of high spatial frequencies than during the processing of low spatial frequencies. The specialized processing of different spatial frequencies in controls is a robust finding, being also seen in adults (Kenemans, Baas, Mangun, Lijffijt, & Verbaten, 2000). However, in children with PDD the same source was activated for both high- and low spatial frequencies, indicating a decreased specialization for the processing of visual spatial frequencies.

Face Processing

Abnormal looking at a person's face during social interactions is a characteristic of PDD. A recurrent theme in PDD research therefore is the question whether subjects with PDD process faces differently from healthy controls. Such atypical processing could be reflected by the absence of the characteristic gaze pattern of fixating mainly eye and mouth regions that is seen in normal controls, or by abnormal face related ERP activity, the N170. Several studies have used infrared corneal reflection techniques to determine the scan paths of control subjects and subjects with PDD while viewing faces. In a study with static stimuli, it was found that both control children and children with PDD, matched for age and IQ, looked at the eye and mouth regions longer than the other parts of the face (Van der Geest, Kemner, Verbaten, & van Engeland 2002a). In addition, a study of scan paths in response to static human figures showed no differences between school-age children with PDD and age- and IQ-matched controls (Van der Geest, Kemner, Camfferman, Verbaten, & van Engeland 2002b). However, in a study using dynamic stimuli (film clips), it was found that adolescents with autism, matched for VIQ and age with control subjects, showed reduced scanning of the eye region and increased focus on the mouth region (Klin, Jones, Schult, Volkmar, & Cohen, 2002). It is possible that the differences in eye gaze behavior between subjects with PDD and controls in the latter study are related to extra processing in the dorsal stream, which is involved in the processing of motion (Kemner & van Engeland, 2003).

ERP studies of face processing have provided little evidence of abnormal face-specific activity in subjects with PDD. In a study of the effect of familiarity of photographs of faces in 3- to 4-year-old children, it was found that in control children (matched for age, not IQ) the amplitude of the P3 or the Nc was affected by familiarity with the face, but this was not seen in the PDD group (Dawson, Carver, Meltzoff, Panagiotides, McPartland, & Webb, 2002). However, both the Nc and the P3 (called P400 in this study) are mainly sensitive to stimulus deviancy and task relevance, and do not reflect face-specific activity. Therefore, this study does not provide evidence of atypical face processing in PDD. In a study with autistic adults and age- and IQ-matched controls, no differences between groups were found with respect to the amplitude of the N170, although individuals with autism exhibited longer N170 latencies in response to faces than did the control individuals (McPartland, Dawson, Webb, Panagiotides, & Carver, 2004).

The aforementioned studies do not provide clear evidence of atypical processing of the face per se. An alternative explanation for the clinical abnormalities seen in gaze behavior in PDD is that the core problem of PDD is the processing of emotional expressions. Several studies, both of gaze patterns and ERPs, have manipulated the emotional expression of faces. In the study of visual scan paths mentioned earlier, emotional expression was manipulated as well. An effect of emotion was found on scan paths—the mouths of happy and surprised faces were looked at longer and more often than the mouths of angry and neutral faces, but no differences were found between groups (Van der Geest *et al.*, 2002a, b). In contrast, a study of adults with PDD and a control group (not matched for age or IQ) showed that subjects with PDD viewed non feature areas of faces with emotional expressions significantly more often and core feature areas of faces (i.e., eyes, nose, and mouth) significantly less often than did control participants (Pelphrey, Sasson, Reznick, Paul, Goldman, & Piven, 2002). However, since the groups were not matched for age and IQ, these effects are difficult to interpret. Emotional expression was also manipulated in an ERP study of 3- to 4-year-old children with PDD and chronological- or mental age-matched controls. Control children showed differences in activity around 300 and 1000 ms in response to fearful and neutral faces, whereas children with PDD did not (Dawson, Webb, Carver, Panagiotides, & McPartland, 2004). However, again it is difficult to interpret the relevance of this finding since it is not known how specifically this ERP activity is related to face or emotion processing. The data suggested that differences in processing between the groups already occurred at very early latencies, suggesting early perceptual processing was atypical in the PDD group.

One ERP study investigated the role of visual spatial frequencies in abnormal face processing in PDD. Groups of age- and IQ-matched control children and children with PDD were presented three stimulus types, namely faces, houses, and stimuli for which children with PDD were experts (reflecting the specific restricted interests of each child). All stimuli were filtered and contained either mainly high or low spatial frequencies. In addition to the measurement of amplitude and latency of the N170, the sources of this peak were determined as well. No differences in either the amplitude or latency of the N170 in response to faces were found between the groups. However, in control children, stimuli containing low spatial frequencies led to activation of anteriorly located sources of the N170 for the processing of faces whereas more posteriorly located sources were activated for the processing of houses and expert stimuli. This effect of stimulus category was not seen if the stimuli contained mainly high spatial frequencies. In contrast, in PDD children similar posterior N170 sources were activated by all stimulus types in both the low and the high-pass filtered conditions (Boeschoten, Kemner, Kenemans, & Engeland, in preparation). Also, an eye movement study has indicated that subjects with PDD show an atypical gaze behavior in response to inverted faces (Van der Geest *et al.*, 2002a, b). There is evidence suggesting that the inversion effect is mediated by low spatial frequencies (Goffaux, Gauthier, & Rossion, 2003).

These results indicate that perceptual factors are involved in abnormalities in face processing in PDD, and suggest that there is diminished specialization of spatial frequency processing of faces in PDD.

DISCUSSION

We reviewed ERP and eye movement studies related to attentional and perceptual processing in PDD. Most of the early ERP studies involving subjects with PDD aimed to determine the effects of deviancy and/or novelty manipulations on attentional orienting. Although some studies reported that subjects with PDD show less long-latency activity (mostly reflected in the P3 peak) in response to infrequently occurring stimuli, these findings are not consistent. A serious problem in the interpretation of these studies is that subjects were not matched for IQ and age, and there is evidence that the amplitude of the P3 is sensitive to these variables (e.g. Polich & Herbst, 2000; Walhovd & Fjell, 2003). The only study in which subjects were age and IQ matched (Kemner *et al*., 1994) did not find differences between control and PDD groups in this respect. Additionally, there are no indications that subjects with PDD have a decreased processing capacity (Hoeksma *et al*., in press; Kemner *et al*., submitted). ERP studies of the ability to focus attention on a specific channel of information have also failed to find consistent evidence of abnormal attentional processing in subjects with PDD (Ciesielski *et al*., 1990, 1995; Hoeksma *et al*., in press). Likewise, the results of eye movement studies suggest that attention shifting is normal in subjects with autism (Kawakubo *et al*., 2004; Van der Geest *et al*., 2001;), although there is some evidence that (covert) peripheral attention is abnormal (Townsend *et al*., 2001). Behavioral studies have shown subjects with PDD to have a variety of abnormalities in attentional processing (e.g. Allen & Courchesne, 2001). However, ERP and eye movement research do not provide consistent evidence that abnormalities in attentional processing are a core feature of PDD.

Several studies have indicated that the atypical processing of visual stimuli in PDD might occur at a perceptual level, since ERP studies have provided evidence that activity over the modality-specific cortex is abnormal already at an early stage of processing (Boeschoten *et al*., submitted; Hoeksma *et al*., in press; Kemner *et al*., 1994; Verbaten *et al*., 1991). In all these studies, except for one (Verbaten *et al*., 1991), subjects were age and IQ matched with control subjects, thereby excluding the possibility that ERP differences between groups might be related to these potentially confounding factors. The smaller occipital amplitudes in PDD children are seen early in processing, occurring at about 100 ms (although the occipital P1 was not determined by Kemner *et al.* (1994), the data indicate group differences in amplitude at this latency). The smaller occipital activity was present regardless of the stimulus type (Boeschoten *et al*., submitted; Hoeksma *et al*., in press), although in one study it was present only with passively attended standards (Kemner *et al*., 1994).

The significance of these findings is unclear. One explanation is that the morphology of the brain is different in children with autism (see e.g. Palmen & van Engeland, 2004), and that occipital generators of the P1 do not have the same location or orientation in healthy children and in children with PDD. A small difference in the orientation of the P1 source would affect the activity measured over the scalp, since EEG is sensitive to source orientation. Another possibility is that different brain regions are activated in clinical and control groups at the P1 latency. This was investigated in a study in which the sources of the abnormal P1 activity in response to stimuli in a selective attention task were determined in control and PDD subjects. Averaged dipole locations were transformed to Talairach coordinates, allowing the mapping of P1 sources to anatomically defined brain areas. However, although the data suggest that the P1 dipoles in young controls were located in the lingual gyrus, and the dipoles in the PDD group were located in the middle occipital gyrus, no significant differences between groups were found (Hoeksma, Kenemans, Kemner, van Engeland, 2005). Interestingly, a study in which the spatial frequency content of grating stimuli was manipulated showed comparable, and significant, differences in source localization between groups (Boeschoten *et al*., submitted). In this study, the sources of early occipital negativity, the N80, were determined in response to high and low spatial frequency gratings. Control children showed distinct source configurations of the N80 for either grating type, in agreement with studies indicating that high spatial frequencies and low spatial frequencies are processed in different brain areas (Hughes *et al*., 1996; Schiller & Logothetis, 1990). The sources for low spatial frequencies were located on the edge between the medial occipital gyrus and the superior occipital superior gyrus. A source in the lingual gyrus explained most of the activation in response to high spatial frequencies; however, in children with PDD the source in the occipital gyrus was activated in response to both stimulus types (Boeschoten *et al*., submitted).

These findings imply that the abnormal early brain activation that occurs during the processing of visual stimuli in children with PDD is probably related to the spatial frequency content of the stimuli. Moreover, there is decreased specialization in the processing of specific stimulus characteristics, i.e. spatial frequency, in children with PDD that are related to detail and global stimulus processing. There are indications that atypical spatial frequency processing also occurs in the processing of faces in children with PDD. As discussed earlier, high and low spatial frequencies are processed in specific pathways, and there is evidence that both pathways are differentially involved in the processing of faces as well.

The localization of abnormal early ERP activity related to spatial frequencies in the lingual cortex in subjects with PDD (see above) is another indication that atypical spatial frequency processing and atypical face processing are associated in PDD, although it should be noted that the spatial resolution of ERP source localization is restricted and absolute localizations are problematic. The lingual cortex is probably involved in face processing, since several studies have shown face-selective electrical activity in this brain area (Allison *et al.*, 1999; Shibata *et al.*, 2002). Also, the lingual gyrus has been observed to be sensitive to biological motion (Servos, Osu, Santi, & Kawato, 2002). Interestingly, a study has shown activation of the lingual gyrus during the observation of a specific kind of motion, so-called second-order motion (Smith, Greenlee, Singh, Kraemer, & Hennig, 1998). Abnormalities in second-order motion perception have been reported in autism (Bertone, Mottron, Jelenic, & Faubert, 2003).

There is reason to believe that, besides in grating and face tasks, atypical processing of visual spatial frequencies is also involved in other tasks in which subjects with PDD differ from controls. For example, subjects with PDD show superior performance in tasks involving hierarchical letters (Navon task) (Plaisted, Swettenahm, & Reese, 1999, but see Mottron, Burack, Stauder, & Robaey, 1999). There is accumulating evidence that performance in such tasks is mediated by the processing of specific spatial frequencies (Badcock, Whitworth, Badcock, & Lovegrove, 1990; Hughes *et al.*, 1996; Lagasse, 1993). Interestingly, autistic and Asperger children were recently found to be better in identifying faces that consisted of high spatial frequency information than in identifying faces that consisted of low spatial frequency information, unlike developmentally healthy children (Deruelle, Rondan, Gepner, & Tardif, 2004).

Abnormal processing of visual spatial frequencies in PDD could be related to an abnormal development of the dorsal or ventral stream. These two visual pathways develop mainly in the first two years, albeit at different speeds (Atkinson, 1992). In this same age range, abnormal brain growth is noted in children with PDD, providing extra evidence for abnormal development of specific brain areas. However, it is not clear whether the dorsal or the ventral stream is specifically affected. Other experimental (behavioral) data have been interpreted as evidence for either a dorsal stream deficiency (Bertone *et al*, 2003; Blake,Turner, Smoski, Pozdol, & Stone, 2003; Milne *et al.*, 2002; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005; Spencer *et al.*, 2000) or for abnormal processing in the ventral stream (Plaisted *et al.,* 1999). However, the data in this review do not indicate a specific abnormality in either high or low spatial frequency processing, but point to a decreased specialization of the visual pathways for specific spatial frequencies. Further studies are needed to determine more specifically the effects of such decreased specialization on other aspects of processing.

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