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fMRI evidence for dorsal stream processing abnormality in adults born preterm

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ABSTRACT

We investigated the consequences of premature birth on the functional neuroanatomy of the dorsal stream of visual processing. fMRI was recorded while sixteen healthy participants, 8 (two men) adults (19 years 6 months old, SD 10 months) born premature (mean gestational age 30 weeks), referred to as Premas, and 8 (two men) matched controls (20 years 1 month old, SD 13 months), performed a 1-back memory task of Object or Grip information using a hand grasping a drinking vessel as stimulus. While history of prematurity did not significantly affect task performance, Group by Task analysis of variance in regions of interest spanning the occipital, temporal and parietal lobes revealed main effects of Task and interactions between the two factors. Object processing activated the left inferior occipital cortex and bilateral ventral temporal regions, belonging to the ventral stream, with no effect of Group. Grip processing across groups activated the early visual cortex and the left supramarginal gyrus belonging to the dorsal stream. Group effect on the brain activity during Grip suggested that Controls represented the actions' goal while Premas relied more on low-level visual information. This shift from higher- to lower-order visual processing between Controls and Premas may reflect a more general trend, in which Premas inadequately recruit higher-order visual functions for dorsal stream task performance, and rely more on lower-level functions.

1. Introduction

Advances in perinatal and neonatal care over the last 30 years have significantly increased the survival rate of babies born very prematurely (Iacovidou, Varsami, & Syggellou, 2010) and potential long-term neurologic and cognitive morbidities are currently being characterized (Allen, 2008). In particular, it has been argued that premature birth is associated with a vulnerability in the dorsal stream of visual processing (Atkinson & Braddick, 2007).

One description of visual processing holds that two anatomically distinct pathways originating in the posterior occipital Brodmann areas 17 and 18 specialize in different functions. The ventral stream, in the temporal cortex, specializes in object perception, while the dorsal stream, in the parietal cortex, uses visual information to control actions (Milner & Goodale, 2006). In a classical double dissociation, patients with damage to ventrolateral occipitotemporal regions are impaired in recognizing objects or estimating their size, but can handle them correctly (visual agnosia), while patients with lesions in the posterior parietal cortex are impaired in visuomotor transformation without disorders in object recognition (optic ataxia, Perenin & Vighetto, 1988).

Greater impairments of dorsal stream functions have been shown in a number of neurodevelopmental diseases, of genetic origin (Williams syndrome, Fragile X) or resulting from perinatal events (premature birth), leading to the hypothesis of a dorsal-stream vulnerability in neurodevelopmental syndromes (Atkinson & Braddick, 2011). For example, a dissociation between ventral and dorsal streams of visual processing was recently demonstrated in 6–9 years old children born very premature (Santos, Duret, Mancini, Gire, & Deruelle, 2009). In this study, visuomotor skills, that rely on dorsal stream functions, were assessed by investigating the copying of a target, composed of local elements (for example, circles) spatially organized to form a global shape (for example, a square). Results indicated that preterm children were significantly impaired in copying the stimuli, with a positive correlation between their copying scores and gestational age. Perceptual skills were assessed using a task requiring to match the same targets to one of two visually presented items matched either in terms of local elements or of global shape. Children born preterm did not differ from controls in their choice bias, suggesting both groups relied similarly on global information. Another experiment reported impaired pointing movements in 10-years-old children born preterm (Van Braeckel et al., 2008). These findings of specific visuomotor impairments, as well as the report of specific delays in many systems within the visuomotor, spatial and attentional domains (Atkinson & Braddick, 2007), support the hypothesis of a vulnerability in the dorsal stream of visual processing in individuals born premature.

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The distinction between dorsal- and ventral-stream vulnerabilities in development implies that different mechanisms and/or timings affect the plasticity of temporal and parietal association areas. It was suggested that ventral stream regions rely on general, associative learning mechanisms to adapt and learn new objects through life, while dorsal stream regions, that compute dynamic relations between objects (including body parts) would be plastic only during a limited period in the course of development (Neville & Bavelier, 2002). In this framework, the effects of atypical early visual stimulation associated with premature birth on the experience-based maturation of the brain would have more consequences on dorsal than on ventral stream functions. Consequently, adults born preterm can serve as models of the dorsal stream vulnerability and have become the focus of neuroimaging studies (e.g. Narberhaus et al., 2009).

Here, we used fMRI to measure local variation of cerebral blood flow using an experimental paradigm enabling a direct comparison of dorsal and ventral stream functions (Shmuelof & Zohary, 2005). In the first task, participants needed to process the identity of an object ("What" is the object grasped?), an ability sustained by the ventral stream. The second task required the identification of the grip used to grasp an object ("How" is the object grasped?), an action recognition task that has been shown to activate regions of the dorsal pathway. Both tasks utilized the same stimuli and stimuli sequences, so that only task-related attention to the object or to the hand-object relationship was associated with ventral and dorsal stream functions respectively. We hypothesized that the ventral task would activate clusters in the temporal lobe, in particular in the posterior lateral and ventral regions involved in objet perception, and the dorsal task the parietal lobe in and around the anterior intraparietal sulcus, similar to the regions responding to object and grasp adaptation (see Fig. 7 in Shmuelof & Zohary, 2005).

Because the participants born premature included in this experiment were healthy, we did not expect greater difficulties compared to controls to perform the task, but considering the dorsal stream vulnerability hypothesis, we predicted that they would recruit different processes, associated with differences in brain functional anatomy, to perform the task. How could the dorsal stream vulnerability associated with premature birth be reflected in the functional neuroanatomy of the dorsal stream? According to the hypothesis that the early dorsal stream maturation is perturbed by premature birth, we expected to find evidence of reduced specialization in the parietal areas recruited by the dorsal stream task, but no effect of premature birth in the ventral stream areas recruited by the ventral stream task. This reduced specialization would lead to cluster(s) in the parietal lobe being associated with the dorsal stream task in controls, but not in adults born preterm.

2. Methods

2.1. Participants

Sixteen right-handed participants gave written informed consent to participate in this experiment that was approved by the local ethics committee Marseille-I: eight individuals (two men) born preterm (Premas), 19 years 6 months old, SD 10 months; eight Controls (two men), 20 years 1 month old, SD 13 months, with no significant age difference between groups in independent two-sample *t*-tests $p = 0.234$ ($\eta_p^2 = 0.10$). Gestational age at birth differed significantly between the two groups (Premas: 30 weeks old, SD 2; Controls: 39 weeks old, SD 1; $p < 0.001$; $\eta_p^2 = 0.91$). The eight participants in the Premas group were contacted on the basis of their medical records, all of them had normal repeated cranial ultrasound during perinatal hospitalization and a normal neurologic examination at discharge and at the time of scanning. Premas were asked to come with their "best friends" to match Controls on age and socioeducative background individually. All participants were right handed and had normal vision.

2.2. Experimental paradigm

The experimental paradigm was adapted from Shmuelof and Zohary (2005). Stimuli consisted of a left hand grasping drinking vessel. There were four series of drinking vessels (stemmed glasses, tumblers, cups, mugs) and, in each series, three different objects, three different grips, and two different wrist angles, leading to a total of $3 \times 3 \times 2 = 18$ different stimuli per series. The grips were a power grip, an intermediate grip with three fingers and opposite thumb, and a precision grip. Pictures were presented in black and white with the grasped object at the centre of the screen and a smooth circular gradient from picture to black removing sharp transitions other than the hand grasping the object over a grey background.

An experimental block comprised 18 trials consisting of a complete series of 18 stimuli presented successively 4/3 s each separated by 1/3 s fixation cross. There were two 1-back tasks, in which participants had to judge, for each of the last 17 stimuli of a block, whether either the Grip or the Object was the same as in the previous stimulus, by pressing the appropriate key ("same" with index, "different" with middle finger). Practically, they were asked to report whether the grip in stimulus $n + 1$ was the same as the grip in stimulus n in the Grip task, and whether the cup in the stimulus $n + 1$ was the same as the cup in stimulus n in the Object task. The same stimuli and sequences were used for the two tasks, with 8 or 9 "same" responses, counterbalanced to have an average of 8.5 "same" responses across all blocks in both tasks. There were four Grip and four Object blocks per session and four sessions, resulting in a total of 16 Grip and 16 Object blocks. Each block started with a 2-s written reminder of the Task and was followed by a 3-s interblock interval. Three 18-s Rest periods were interspersed after active blocks 2, 4 and 6.

2.3. MRI acquisition

Data were collected with a 3T BRUKER MEDSPEC 30/80 AVANCE scanner (Ettlingen, Allemagne) running ParaVision 3.0.2 at Marseille Cerebral Functional MRI centre. Stimuli were projected on a mirror located in front of the participants' eyes. Responses were recorded with a 5-digit keyboard. Control of stimulus presentation and recording of responses was performed in LabView 8.6.

A high-resolution T1-weighted 3D image was acquired for each participant (MPRAGE, FOV $256 \times 256 \times 180$ mm^3, voxel size $1 \times 1 \times 1$ mm^3, TR 9.4 ms, TE 4.424 ms, $\alpha = 30°$), followed by a fieldmap using a double echo FLASH sequence (FLASH, FOV $192 \times 192 \times 192$ mm^3, voxel size $3 \times 3 \times 3$ mm^3, TR 30.0 ms, TE 3.700 ms, $\alpha = 30°$) and four functional runs (EPI, FOV 192×192 mm^2, pixel size 3×3 mm^2, 36 3-mm thick interleaved ascending axial slices without gap, TR 2400 ms, TE 30 ms, $\alpha = 81.6$, 142 repetitions).

2.4. fMRI data analysis

Analysis was performed with SPM8. After discarding the first five EPI images, slice-timing correction was followed by realignment and unwarping procedures to correct for both the static distortions of the magnetic field with the voxel displacement map obtained from the fieldmap toolbox and the movement-induced distortions of the time series (Hutton et al., 2002). The mean image created was coregistered with the anatomical image, which was used to normalize all functional data, then smoothed with a Gaussian kernel of 9 mm FWHM.