Investigating the Need and Feasibility of Cardiac Triggering for Diffusion Imaging Data in Neonatal Subjects

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Introduction: Magnetic resonance imaging has been in increasing use for neonatal and young pediatric subjects (1). The examination protocol often includes diffusion-weighted imaging (2) to examine the white matter microstructure both in normal development and in the injured state (3). Diffusion weighted images are susceptible to artifacts due to tissue movement related to cardiac pulsation. It has been shown that cardiac triggering can improve the quality of diffusion-weighted data in adults (4;5), however it also results in extended acquisition time unsuitable for general clinical applications. Given the high heart rate of neonates, cardiac triggered image acquisition might be performed on a reasonable timescale; nevertheless, diffusion-weighted imaging usually proceeds without it. Our aims were to (a) examine the presence and extent of pulsation artifacts in diffusion-weighted images collected from neonatal subjects; (b) quantify their effect on the derivatives of the data (fractional anisotropy [FA], apparent diffusion coefficient [ADC], and fiber orientation); and (c) test feasibility of cardiac triggered acquisition in this patient group.

Methods: *Subjects:* Six young children and infants were involved (age range 1-13 months, 4 girls) each of which was in need of a clinical MRI examination. With the approval of the local ethics committee and the consent of the parents we supplemented the clinical scanning session with one of two acquisition protocols.

Data Acquisition: Images were collected on a 3T Philips Achieva Scanner (Philips Medical Systems, Best, The Netherlands) using an 8-channel receive only head coil employing the Stajskal-Tanner diffusion encoding and echo-planar data collection methods. The b-value was 0 s/mm^2 for the reference image and either 1000 or 800 s/mm^2 for the diffusion-weighted images. Parallel imaging (SENSE) was employed with an acceleration factor of 2. The infants were sedated using intra-venous propofol; their ECG and O$_2$ partial pressure were constantly monitored by qualified anesthesiologists. Two kinds of different experiments were performed.

In _Experiment 1_, two sets of 21 image volumes were collected from two subjects (1 female), each containing a reference image and 20 diffusion weighted images with diffusion encoding along the z gradient axis (30 slices; slice thickness: 3 mm; slice gap: 1.5 mm; FOV: 240 mm; in-plane resolution: 3 x 3 mm^2).

In _Experiment 2_, two sets of 16 image volumes were collected from three infants (2 female), each containing a reference image, and 15 diffusion-weighted images with diffusion directions distributed as implemented by Philips (40 slices; slice thickness: 2.5 mm; no gap; FOV: 200 mm; in-plane resolution: 2.5 x 2.5 mm^2). In both experiments, the acquisition of the first set of images was cardiac triggered (i.e. a single image was collected per heart-beat with at least 160 ms delay (4)) using the vector ECG available on the scanner. The total time of this acquisition was recorded and for the second acquisition TR was set to give the same total acquisition time. For one subject (1 month, girl) a variant of _Experiment 1_ was performed where both acquisitions were cardiac triggered to examine test-re-test variability.

Data processing: The data from _Experiment 1_ was put through a bootstrap statistical procedure in Matlab 7.5 (MathWorks Inc., Natick, MA, USA) as previously reported by Nagy et al. (6) to examine whether the variance was reduced in the data by cardiac triggering the acquisition. The threshold for statistical significance was set at 0.001 without correction for multiple comparisons. The data collected in Experiment 2 were used to fit the tensor as implemented in the FSL software (FMRIB, University of Oxford, UK). From the tensor, FA and ADC and color coded images representing the direction of the first eigenvector were calculated.
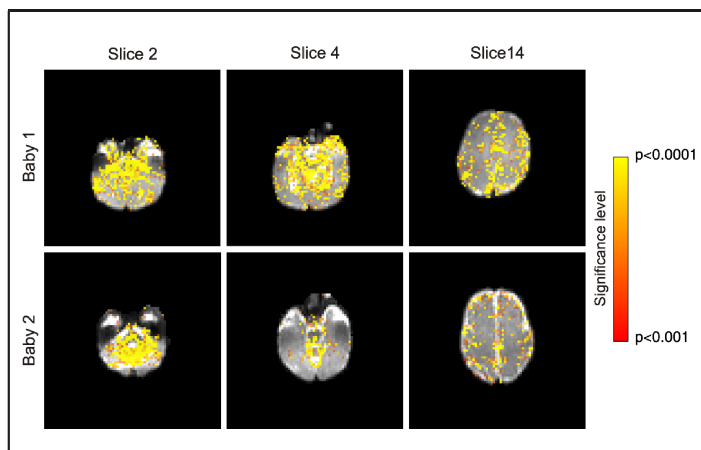

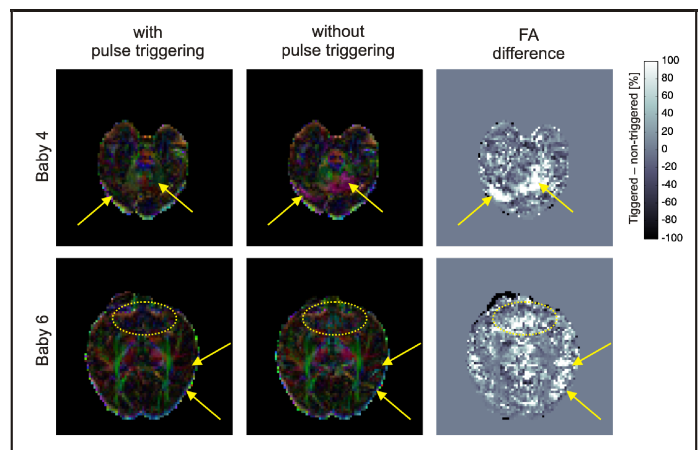**Figure 1 – Results of bootstrap analysis in representative slices**

Figure 2 – Examples for differences in FA and tract orientation

Results: _Experiment 1:_ The data from two different subjects show large areas where the voxel-wise variance in the repeated measurement of diffusion along the z gradient axis is statistically significantly larger when cardiac triggering is not used (Figure 1). Contrary to investigations in adults (4) this effect is observable even in superior slices. If the same bootstrap statistics is subjected to repeated measurements of the data with cardiac triggering only a few voxels survive the same threshold of statistical significance (data not shown).

Experiment 2: If the tensor model is fit to the non-triggered dataset both the FA values and the fiber orientations can attain artifactual values that may be hard to identify as erroneous unless the comparison is pointed out (Figure 2).

Discussion: In conclusion, cardiac triggering the acquisition of diffusion-weighted data results in decreased variance and more reliable estimation of the diffusion tensor. Another means for eliminating data with pulsation artifacts is collecting the entire dataset more than once and subsequently compiling a single set of images without the artifacts, but this approach results in long acquisitions. As the brain of neonates and young children are relatively small, fewer slices are enough to achieve full-brain coverage, thus allowing a volume-to-volume minimum TR of only 2-3 seconds. Since such a short TR does not allow appropriate relaxation of the longitudinal magnetization, investigators usually collect data with TR set to about 6-8 seconds (e.g. Counsell et al.,2006 (7)). Because of the high heart rate of neonates the volume-to-volume TR with cardiac triggered acquisition is in similar time range, thus besides helping to eliminate artifacts from the data cardiac triggering also provides an opportunity for more complete T1-relaxation and optimum signal-to-noise ratio. As fitting the ECG triggering is simple and fast, although in our experience it requires some practice, the benefits of cardiac triggering in neonates surpass the inconvenience of slightly elevated acquisition time.

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