


Prospective Head-Motion Correction Improves the Quality of Anatomical Brain MRI in Naturally Sleeping Infants

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Impact

Prospective motion correction enhances image quality in naturally sleeping infants' brain MRI, yielding sharper images and more reliable cortical morphometry, thereby improving the validity of early-life neuroimaging biomarkers and fostering standardized, motion-aware, sedation-free pediatric imaging protocols.

Synopsis

Motivation: Head motion strongly degrades infant brain MRI, introducing artifacts that alter image quality and bias brain morphometric measurements during the first year of life.

Goals: To assess whether prospective motion correction improves image quality and quantitative morphometry in sleeping infants.

Approach: Sixty infants (3-12 months) were scanned at 3T using a markerless optical head-motion tracking system enabling real-time MRI's field-of-view updates. Corrected and uncorrected images were compared using quantitative metrics, expert visual ratings, and cortical thickness analyses.

Results: Motion correction improved T2w sharpness and contrast, enhanced overall T1w-images quality, and reduced cortical thickness overestimation.

Introduction

Magnetic resonance imaging (MRI) offers unique insight into early brain maturation, providing high-resolution, quantitative information essential for typical and atypical neurodevelopment study. However, obtaining high-quality images in infants scanned without sedation remains challenging due to their small head size, involuntary movements and poor contrast. Motion artifacts cause blurring, ghosting, and segmentation errors that degrade both qualitative and quantitative analyses, potentially biasing developmental trajectories.

While passive approaches, such as immobilization, or rapid imaging, can reduce artifacts, they cannot correct for motion once it occurs. Active motion correction methods, including MR navigators and optical tracking systems, have proven effective in adults¹⁻³, but remain largely unexplored in infants. This study is the first that aims to quantify the impact of prospective optical motion correction on anatomical image quality and brain morphometric reliability in naturally sleeping infants aged 3 to 12-months.

Methods

Sixty anatomical scans of healthy infants (3, 6, and 12-months) were acquired during natural sleep on a 3T Siemens Prisma with a 64-channel head coil. A markerless optical tracking system (Tracoline, TracInnovations, Denmark)⁴ was used to track head motion in real time to update the field-of-view and trigger selective reacquisition when motion exceeded 0.5mm (T1w-images) or 0.4mm (T2w-images).

T1w and T2w-images used 3D MP-RAGE and T2-SPACE sequences, both at 0.8mm isotropic. For each scan, two reconstructions were generated: a prospectively motion-corrected image, and a synthetically uncorrected image obtained by applying inverse motion parameters during k-space reconstruction to simulate the absence of correction^{5,6}. Image-quality metrics included Tenengrad sharpness⁷ and gray-white matter contrast-to-noise ratio (CNR).

Two blinded experts rated each corrected/uncorrected image pair on noise, sharpness, and ghosting using a 0-2 scale per criterion (2=superior image, 0=inferior, 1=equivalent). Brain segmentation and surface reconstruction were performed using a dedicated pipeline, leveraging iBEAT v2.08⁸ and FreeSurfer⁹ tools. Linear mixed-effects models¹⁰ assessed effects of correction, motion, and age on image-quality and morphometric outcomes, with pairwise comparisons using *emmeans*¹¹.

Results

Head-motion amplitudes summarized as composite motion scores¹² (mm/min) and classified as low, medium, or high-motion (Figure-1). Tracking data revealed a broad range of motion magnitudes across scans, from subtle respiratory drifts to larger, sporadic displacements (Figure-2). Low-motion scans were dominated by rhythmic Z-translations and X-rotations linked to breathing, while medium- and high-motion scans showed additional slow drifts and abrupt head shifts.

Prospective correction significantly improved objective quality metrics for T2w-images (Figure-3A). Tenengrad sharpness and WM/GM-CNR were both higher in motion-corrected T2w-images ($p < 0.001$) and scaled with motion severity, with the largest gains in high-motion scans. No overall difference was observed for T1w-metrics, although moderate benefits appeared in high-motion cases.

Expert visual ratings mirrored these findings: for T2w-images, corrected scans were consistently rated sharper, less noisy, and showing reduced ghosting ($p < 0.001$ across motion levels), while T1w improvements were significant especially in medium- and high-motion groups ($p < 0.01$, Figure-3B). Figure-4

presents typical head-motion curves and the effects of correction on T2w-images.

Motion correction also reduced systematic biases in brain morphometric measurements (Figure-5). Regional cortical thickness analysis revealed lobe-specific vulnerability: overestimation was strongest in the frontal and occipital lobes at 3-6 months (medium-motion $d \approx 0.4$; high-motion $d \approx 0.26$, $p < 0.01$), and again at 12-months ($d \approx 0.57$, $p < 0.001$). Parietal overestimation appeared at 3-6 months ($p < 0.05$), while the temporal lobe showed motion-dependent estimation trend reversals, consistent with segmentation instability. Overall, corrected reconstructions produced lower and more anatomically plausible cortical measures across all age groups.

Discussion

This is the first brain MRI study to assess active head-motion correction in infants aged 3-12 months. In neonates, the close anatomical proximity of the thorax and head causes respiratory movements to degrade brain image quality more than in adults, producing gradual light translation of the head, and likely the entire infant, along the z-axis toward the MRI bore, with the higher spatial resolution required to image the smaller infant brain further increasing sensitivity to motion.

Expert qualitative ratings demonstrated that prospective motion correction improved both T1w- and T2w-images, whereas quantitative metrics failed to capture benefits for T1w-data, perhaps reflecting the limited applicability of adult-derived metrics to neonatal imaging. Motion artifacts also introduced systematic biases in morphometric analyses, particularly in infants aged 3-6 months. Head-motion affected multiple cerebral lobes, with the frontal and occipital lobes most vulnerable. These findings highlight that prospective motion correction is essential for obtaining reliable, high-quality, sedation-free anatomical MRI during early infancy.

Conclusion

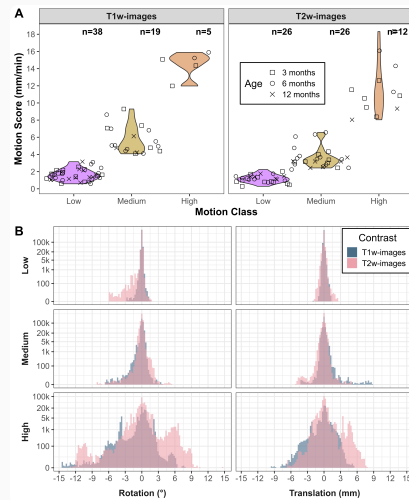
Prospective head-motion correction markedly improved anatomical MRI of infants' brains during natural sleep, producing sharper images and enhanced tissue contrast. Even subtle movements introduced systematic morphometric biases, establishing motion correction as essential for reliable, sedation-free infant brain MRI, especially in the first months of life.

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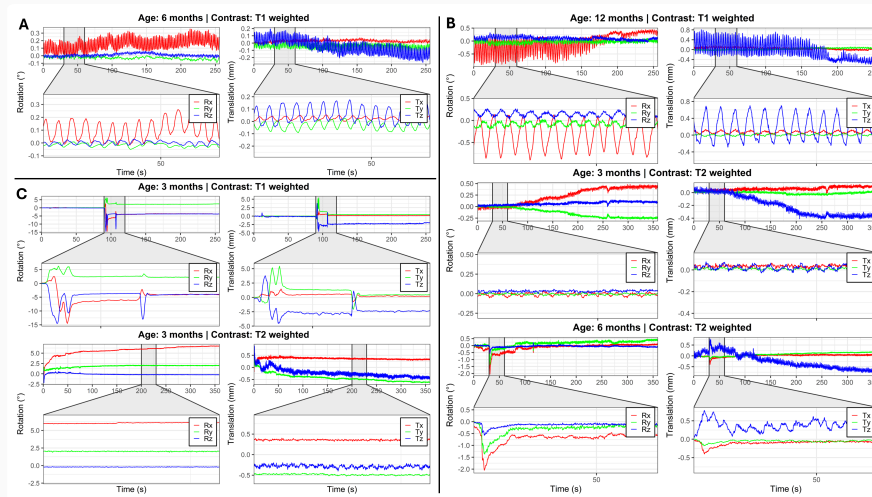
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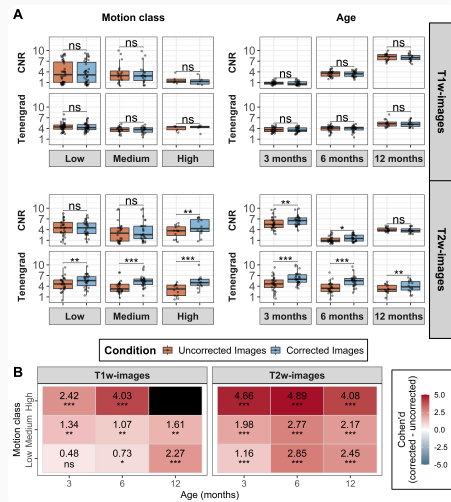
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Figure 1: A) Distribution of head motion scores with class boundaries for T1- and T2-weighted images. B) Histograms of head rotations and translations by motion class across all subjects.



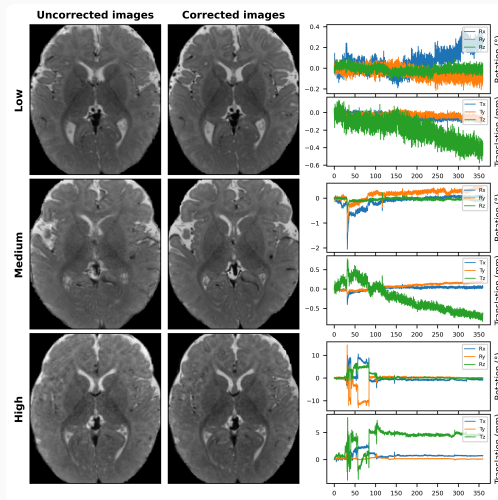
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Figure 2: Head motion traces recorded by the TCL during T1w/T2w infants scans, grouped into low (A), medium (B), and high (C) motion-score categories. Periodic oscillations due to respiration are evident in the z-translation and x-rotation axes. Medium-motion cases additionally show sporadic movements of moderate amplitude. In high-motion scans, two distinct motion patterns appear: 1- slow, continuous drift of head position over time and 2- intermittent, faster displacements with larger amplitudes.



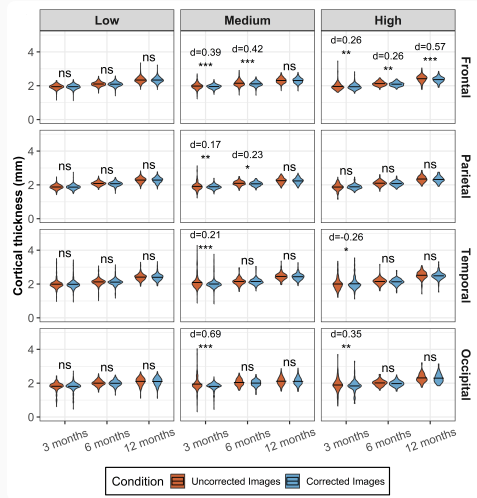
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Figure 3: (A) Effects of motion category and age estimated using a linear mixed-effects model comparing corrected/uncorrected T1w/T2w images based on Tenengrad and CNR metrics. (B) Heatmap displaying effect sizes and corresponding p-values for the combined expert visual ratings across age and motion-score groups for both contrasts. Warm colors indicate higher ratings for motion-corrected images, cool colors indicate higher ratings for uncorrected images, and black squares denote missing data combinations.



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Figure 4: Representative motion-corrected and uncorrected T2-weighted brain images acquired at 6 months of age, displayed across low-, medium-, and high-motion score categories, alongside the corresponding head-motion trajectories recorded during acquisition.



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Figure 5: Head motion effects on cortical thickness derived from uncorrected and motion-corrected images, across cortical lobes, infant ages and motion score classes. Regional comparisons of cortical thickness by lobes show that uncorrected high-motion scans overestimate thickness in multiple lobes (especially frontal) compared to corrected scans. Left: Uncorrected images from head motions Right: Corrected images.