NeuroImage **16,** 89–92 (2002)
doi:10.1006/nimg.2002.1076, available online at http://www.idealibrary.com on IDEAL®

Motion Artifact in Magnetic Resonance Imaging: Implications for Automated Analysis

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Received September 20, 2001

Automated measures of cerebral magnetic resonance images (MRI) often provide greater speed and reliability compared to manual techniques but can be particularly sensitive to motion artifact. This study employed an automatic MRI analysis program that quantified regional gray matter volume and created images for verification and quality control. Motion artifact was assessed on each image and assigned a rating of none, mild, moderate, or severe. Greater motion artifact was associated with smaller gray matter volumes. Severity of motion artifact is an important, but often overlooked, consideration in the interpretation of automated MRI measures. © 2002 Elsevier Science (USA)

Key Words: **brain; magnetic resonance imaging; motion artifact; segmentation.**

INTRODUCTION

As the boundaries of most cerebral structures are the interface of gray matter, white matter, and/or cerebrospinal fluid, morphometry of cerebral magnetic resonance images relies on accurate classification of image voxels into these types. Hand tracing by human raters is time-consuming and may be vulnerable to poor intra and inter-rater reliability. Therefore, there is a strong impetus to apply automated techniques to the quantification of cerebral MR images, especially when dealing with large sample sizes. Advances in image analysis technology have made great strides in improving the reliability and validity of automated techniques.

The technique discussed here uses a probabilistic atlas that classifies tissue according to its location in standardized space combined with an artificial neural network based method that classifies tissue according to voxel intensity (Collins *et al.*, 1999). Face-validity for this technique is high and age, sex, and psychiatric diagnosis effects have been reported based on its output (Castellanos *et al.*, 2001; Giedd *et al.*, 1999, 2001; Paus *et al.*, 1999; Rapoport *et al.*, 1999). However, the effects of motion artifact, frequently present in MR images, on this technique have not previously been addressed. To examine this issue we analyzed gray matter volume from 180 healthy volunteers and, in addition, one healthy volunteer scanned multiple times with varying degrees of motion artifact.

MOTION ARTIFACT

Pharmacologic sedation can minimize movement during scan acquisition but is not appropriate in all situations (e.g., patients with medical contraindications to sedation and, because of the risks associated with sedation, healthy volunteers participating in research protocols).

Mechanical attempts to limit motion, such as placing foam padding around the subject's head, are often inadequate to eliminate mild movement that can result in concentric bands of high intensity on the MR images.

An alternative approach is to measure gross patient motion and correct for its effects during image analysis. Investigators have been working on ways to suppress the effect of motion in an MRI scan, using post-processing techniques that involve the minimization of measures of motion artifact (Atkinson *et al.*, 1999; Hedley and Yan, 1992; Manduca *et al.*, 2000; Su *et al.*, 2001). These methods typically require the acquisition of the frequency domain (k-space) data from the MRI scanner, which is uncommon or even unfeasible in routine acquisition protocols. As such, many MRI researchers are not able to make use of these techniques because they are unable to alter the scanning protocol (e.g., ongoing longitudinal studies) or because these autofocus or autocorrection methods may not be able to correct for all degrees of freedom (e.g., through-plane rotation) of the head motion expected from a child.

Automated measures of gray matter (GM) volumes are especially susceptible to motion artifact because motion blurs image intensities. A narrow, highly convoluted region, such as cortical gray matter, neighboring a comparatively large homogeneous white matter region will tend to "disappear" when blurred by motion. Algorithms designed to quantify GM volume, including the ANIMAL + INSECT (Collins, 1999) method used in this study, typically rely, at least in part, on the

1053-8119/02 $35.00

absolute or relative MR signal. As the gray matter blurs into the surrounding tissues due to subject motion, the results obtained with automated algorithms will also show a reduction in gray matter volume.

To our knowledge, this is the first study that examines the effects of MRI motion artifact on an automated measure of brain anatomy, specifically total and regional gray matter.

METHODS

The subjects for this study were 180 healthy children and adolescents (126 boys and 54 girls; age range 3.6 to 18.3 years) participating in an ongoing longitudinal pediatric brain MRI project at the Child Psychiatry Branch at the National Institute of Mental Health. All subjects gave assent and their parents gave signed consent.

All subjects were scanned on the same GE 1.5 Tesla Signa scanner using the same three-dimensional spoiled gradient recalled echo in the steady state (3-D SPGR) imaging protocol (axial slice thickness = 1.5 mm, time to echo = 5 ms, repetition time = 24 ms, flip angle = 45°, acquisition matrix = 192 × 256, number of excitations = 1, and field of view = 24 cm). Foam padding was placed around the head to minimize scanner noise and help steady the head position. Subjects were scanned in the evening to promote natural sleep; none of the children were pharmacologically sedated. A clinical neuroradiologist evaluated all scans and no gross abnormalities were reported.

The previously described automatic segmentation and classification technique provides lobar (frontal, parietal, temporal, and occipital) parcellation of cortical gray matter volumes and composite images used for verification. Each image was viewed after processing and was assigned a motion artifact rating of none (126 scans, 70%), mild (34 scans, 19%), moderate (12 scans, 7%), or severe (8 scans, 4%; see Fig. 1, for examples). Scans rated as "none" had little or no detectable motion artifact. Those rated as "mild" had enough detectable motion to result in subtle concentric bands to appear in the automated classification (the second row in Fig. 1). Those rated as "moderate" had significant banding while those rated as "severe" were so extreme that the data was deemed unreliable for analyses. A random 10% of the scans were measured a second time to assess intra-rater reliability (Alpha = 0.963) and inter-rater reliability (Alpha = 0.958).

To address confounds of age, individual differences (e.g., gender, race, handedness), and scanner variability, a single subject (a 7-year-old girl) was scanned 16 times in one evening with no specific directions about movement. Although she was unaware of the purpose of the multiples scans, we achieved scans with varying degrees of motion (10 scans with no detectable motion, 2 with mild motion, 1 with moderate motion, and 3 with severe motion), during a single scanning session.

RESULTS

Gender and age are both related to quantitative measures of total and regional gray matter so it was important to assess whether these variables are also related to severity of motion artifact. Gender does not appear to be related to motion artifact in that a similar proportion of scans were flagged as having motion artifact across the sample (9.3% for girls and 11.9% for boys; Pearson Chi-Square = 0.27, $P = 0.61$). We have previously shown that gender is related to cerebral volume (approximately 10% larger in boys; Giedd *et al.*, 1997, 1999). Not surprisingly, age is related to severity of motion artifact ($F = 7.32$, $P < 0.001$) such that younger children had greater motion artifact. The relationship between age and total and regional GM is more complex. In a previous paper employing longitudinal data (Giedd *et al.*, 1999), we demonstrated nonlinear changes in cortical gray matter, with a preadolescent increase followed by a postadolescent decrease.

To address these possible confounding factors, the effects of age and gender were controlled in the following analyses. Greater motion artifact was associated with smaller values of total GM (ANCOVA $F = 6.55$, $P < 0.001$) and regional GM (Frontal GM $F = 8.08$, $P < 0.001$; Temporal GM $F = 8.47$; $P < 0.001$; and Parietal GM $F = 4.48$, $P < 0.01$), even after controlling for age and gender effects. As seen in Fig. 1, scans coded as having no motion artifact had a mean (SD) total GM volume of 727.04 (75.19) ml. Scans flagged as having mild, moderate, or severe motion artifact had decreasing mean (SD) total GM volumes of 714.27 (70.44), 704.83 (29.33), and 582.62 (141.75), respectively.

Representational examples of total GM volume values for the individual subject scanned sixteen times in one evening are presented in Fig. 1. The results for the single subject were similar to those described above for the entire sample. With no motion, the value for total GM was 679.23 ml. As the severity of motion increased through mild, moderate, and severe, the values for total GM decreased 4, 7, and 27%, respectively. Regional GM volumes (frontal, temporal, parietal, and occipital) decreased with increasing motion in the same manner.

DISCUSSION

Increasing degrees of motion artifact decreased the measured values of gray matter volume. Even minimal motion decreased GM values by over 4%. Since this magnitude is within the range of between-group differences in some studies (cf. Castellanos *et al.*, 1996), the importance of quantifying and controlling motion arti-

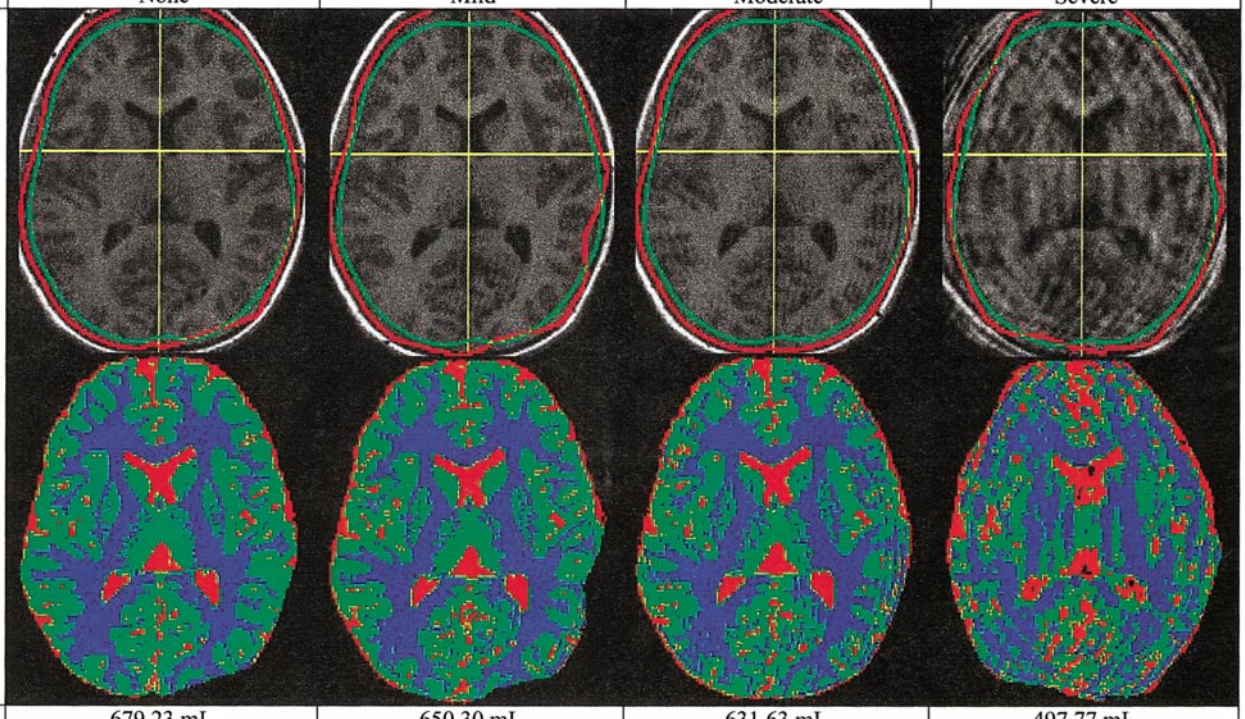
Motion	None	Mild	Moderate	Severe
Example MRI from the same subject / Green=GM Blue=WM Red=CSF				
Total GM Volume for above example	679.23 mL	650.30 mL	631.63 mL	497.77 mL
Total GM Volume for sample	727.04 ± 75.19	714.27 ± 70.44	704.83 ± 29.33	582.62 ± 141.75

FIG. 1. Total GM volume for individual case and for the entire sample.

fact between groups is highlighted. The results described above reflect only a single automated measurement algorithm. It is unknown whether similar results would be found with other segmentation algorithms; however, it is expected that any intensity-based segmentation or classification technique will be affected by motion artifact in a similar fashion.

As brain morphometry studies become dependent on automated measures of brain regions and structures, it is imperative that severity of motion artifact be considered. Furthermore, because younger children are more likely to move in the MRI scanner, resulting in increased motion artifact, studies of brain development are especially susceptible to age-related motion artifact confounds. It is particularly important, therefore, to control for motion artifact in pediatric MRI studies. We are currently investigating whether it is feasible to automatically estimate the severity of the motion artifacts and use these estimates not only for quality control, but also as a correction to the results of specific automated quantitative analysis techniques. Ideally, the motion artifact would be removed before the application of post-processing techniques. However, we are currently unaware of an automated measure of motion artifact that adequately captures and corrects for the range of motion described above, without requiring modifications to existing acquisition protocols. Such an algorithm would be an extremely valuable tool in longitudinal or population studies relying on the morphometric analysis of MRI data.

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