NeuroImage (1999) **9**, S56

Scan order effects in PET activation studies are caused by motion artefact

Matthew Brett[1,2], Peter Bloomfield[1], David Brooks[1], John Stein[2], Paul M Grasby[1]
[1] MRC Cyclotron Unit,London, UK
[2] University Laboratory of Physiology, Oxford, UK

Abstract
It is a frequent observation in PET activation studies that some brain areas show linear changes in signal across the scanning session. These changes have been attributed to changes in cognitive state such as attention. We have investigated this scan order effect using data from three typical activation studies, each from different units and using different tasks.

Methods
Each study consisted of an initial transmission scan, followed by 12 emission scans. Images were reconstructed from sinograms by filtered back projection, after attenuation correction using the transmission data. Each experiment used $H2O^{15}$ bolus injection; condition order was randomized. Study 1, from the MRC Cyclotron Unit, using an ECAT 953B scanner, compared rest to the performance of unfamiliar hand gestures in seven subjects. Study 2, from the Functional Imaging Laboratory ECAT Exact HR+ scanner, compared rest to word listening and repetition, with 8 subjects. Study 3 was from the Wolfson Brain Imaging Centre in Cambridge, using a GE Advance scanner, comparing memory encoding and retrieval tasks in seven subjects. We used the current alpha version of SPM98 for realignment of images. After realignment, we derived realignment parameters for the images for each subject in terms of translations and rotations from the first image, with the origin at the anterior commisure. To investigate the effect of mismatch between the emission and transmission scans, we generated simulated data for each subject in study 1 thus: the first scan in the session was reconstructed without attenuation correction. Using the realignment parameters above, we resliced this image into the space of the second, third etc. image in the session. The resliced images were then forward projected into sinograms, transmission attenuation correction was applied, and the simulated, attenuation corrected sinograms were back projected into images. Statistics were from SPM96. For each analysis, the full experimental design was modeled. Linear time effects were modeled with scan order as a covariate.

Results
Signal changes which covaried with scan order were similar in position and extent across studies. There were widespread increases in gray and white matter frontally, and decreases in the occipital regions. Changes are shown for study 1 in figure 1. The effects were highly significant after correction for multiple comparisons. Three of the six movement parameters were strongly positively correlated with scan order (pitch, yaw and y translation, $p<0.001$) reflecting a consistent movement of the head over the scanning session across subjects and studies. Brain areas showing significant changes related to movement parameters (assessed with the F map) were similar to those related to scan order. Inclusion of the movement parameters in the statistical model for each study caused dramatic reductions on the variance explained by scan order, without equivalent reductions in the effects of activation condition. Adding scan order to a statistical model that already included the movement parameters caused a much smaller reduction in the variance explained by the movement parameters.

Analysis of the simulated images from study 1 was designed to show that scan order effects could be reproduced by applying the initial transmission data to emission scans which had moved out of alignment. As predicted, the simulated data also showed highly significant scan order effects, in a similar position to those found in the original images (figure 2).

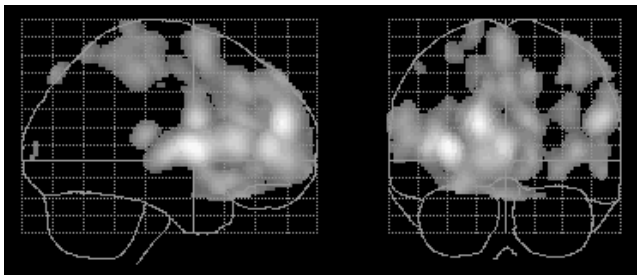

Figure 1: Study 1, signal increases over scanning session

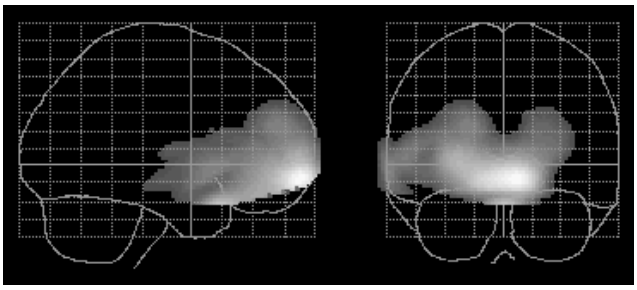

Figure2: Simulated data, increases over scanning session

Discussion

Scan order effects in PET activation studies were consistent across three very different datasets. The position of the effects, which are as prevalent in white as in gray matter, and confluent, suggest that they are not likely to reflect changes in regional blood flow. The strong relationship between scan order and movement parameters raised the possibility that the effects may be movement rather than time related. The fact that the variance explained by scan order was greatly reduced by inclusion of movement parameters in the statistical model, when there was not an equivalent reduction for the movement parameters when scan order was included, suggests that the movement parameters are a better model of the effect than scan order. The simulated data study showed that the scan order effect can be reproduced merely by applying misaligned attenuation correction. This last result strongly suggests that the scan order effect is in fact an artefact of movement across the scanning session. This highly significant artefact may cause difficulties in interpretation of studies where conditions have not been balanced across scan order, or when subject movement is related to activation condition. We propose that investigators reporting PET activation results should report differences in subject movement between conditions, and include movement parameters in their PET statistical model.