Somatotopic mapping within the cingulate motor area: evidence from an ALE meta-analysis of the Stroop task

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Introduction: Controversy exists concerning functional heterogeneity within the cingulate motor area. Previous studies and reviews have examined the role that response modality plays in monitoring conflict in the anterior cingulate (Barch, 2001; Picard and Strick, 1996; Paus, 1993) and found conflicting results. The objective of this study was to study the patterns of convergence in the Stroop color-word task using the activation likelihood estimation (ALE) meta-analysis method (Turkeltaub, 2002; Laird, 2004) in order to resolve the disagreement concerning the presence or absence of somatotopic mapping in the anterior cingulate cortex.

Methods: A literature search identified 19 fMRI and PET studies that investigated the Stroop task in normal subjects. These studies all published their activation results as 3D coordinates (x,y,z) in stereotactic space. 205 coordinates were extracted from these publications and spatially renormalized to Talairach space (Brett, 1999). Activation likelihood estimation (ALE) maps were created as described by Turkeltaub *et al.* (2002) using a FWHM of 10 mm. Statistical significance was determined using a permutation test of randomly distributed foci, corrected for multiple comparisons using the false discovery method (Genovese, 2002). All data processing was performed using an in-house Java version of ALE developed at the Research Imaging Center. Three different ALE maps were computed for all Stroop studies, Stroop studies that required an overt or covert verbal response, and Stroop studies that required a manual response.

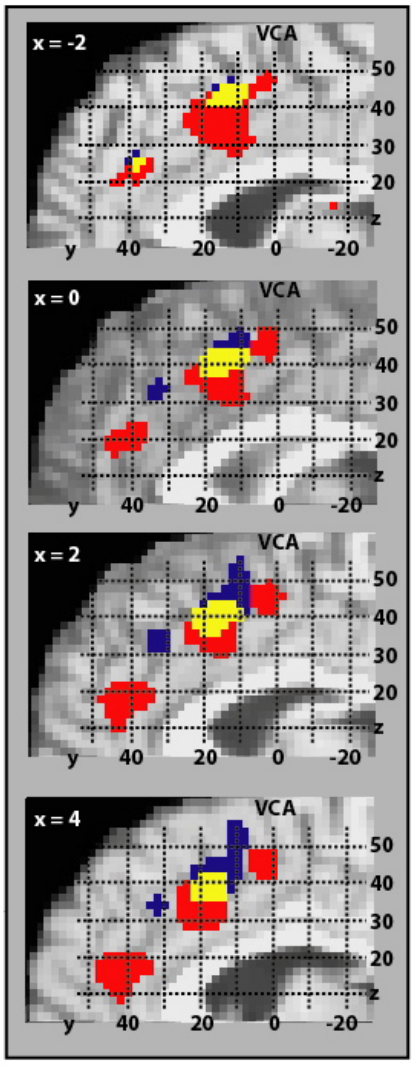

Figure 1. ALE meta-analysis maps (p<0.05) for the Stroop task for verbal (red) and manual responses (blue) and their overlap (yellow) at four slices in the sagittal orientation.

Results: We performed ALE meta-analyses for verbal and manual Stroop (p<0.05) and compared the results to investigate the issue of functional segregation within the cingulate motor area. A high probability for activation was found in regions that extend along the length of the cingulate sulcus, rostral to the vertical plane passing through the anterior commissure (VCA), that clearly display multiple distinct areas for verbal (red) and manual (blue) response types (Figure 1). The motor region of the anterior cingulate is divided into the rostral cingulate zone (rCZ), located anterior to the VCA and superior to the corpus callosum, and the caudal cingulate zone (cCZ), which lies approximately posterior to the VCA. Furthermore, the rCZ is subdivided into an anterior division (rCZa) and a posterior division (rCZp). Two regions of high concordance are seen in the rCZa: one large verbal area near the genu of the corpus callosum (x = 3, y = 41, z = 18) and one smaller manual area, posterior and superior to the verbal region (x = 2, y = 32, z = 34). Additionally, a verbal rCZp region (x = 1, y = 16, z = 36) is located inferior to a manual rCZp region (x = 3, y = 15, z = 43). The verbal rCZp cluster wraps up and around the manual rCZp cluster such that a portion of it lies in the cCZ, near the VCA. The manual region, in contrast, appears to extend towards the pre-SMA and is located completely anterior to the VCA. Finally, we note that there are two regions of overlap between the verbal and manual response types: one large region in the rCZp (x = 2, y = 16, z = 41) and one smaller region in the rCZa (x = -3, y = 37, z = 25).

Discussion: Despite the differences in data and analysis method, the similarities between areas of dissociation between verbal and manual responses in the Picard and Strick review (1996), the Paus *et al*. study (1993), and the ALE meta-analysis presented here are striking. Our ALE results agree with these previous publications in concluding that somatotopic mapping exists in the ACG with multiple regions in the rCZ for hand and speech response types. Two regions were seen in the rCZa: one large verbal area near the genu of the corpus callosum and one smaller manual area, posterior and superior to the verbal region. The manual region of the rCZp, in contrast, appears to extend towards the pre-SMA and is located completely anterior to the VCA, a result that disagrees with the findings of both Paus *et al*. (1993) and Picard and Strick (1996). Our results agree with Picard and Strick and Paus *et al.* concerning the verbal regions in the rCZa and rCZp and Picard and Strick's localization of the hand areas in the rCZ, but they are not consistent with idea that activations associated with manual responses are localized to cCZ.

References

Barch DM, *et al*. *Cereb Cortex*,2001; **11**:837-848.
Picard N, Strick PL. *Cereb Cortex* 1996; **6**:342-353.
Paus T, *et al*. *J Neurophysiol* 1993; **70**:453-469.
Turkeltaub PE, *et al*. *Neuroimage* 2002; **16**:765-780.
Laird AR, *et al*. *Proc. ISMRM* 2004; Kyoto, Japan.
Brett M. 1999; http://www.mrc-cbu.cam.ac.uk/Imaging/mnispace.html.
Genovese CR, *et al*. *NeuroImage* 2002; **15**:870-878.