Functional reorganization of visuo-motor cortical networks in Formula 1 pilots versus naive drivers

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Introduction:

Professional racing pilots recruited a significantly lesser extent of task-relevant brain areas as compared to naive drivers during simple visuo-motor tasks, despite equal levels of performance [7]. This more parsimonious cortical recruitment, found also in other highly skilled groups [6,8], may reflect a greater neural efficiency associated with expertise and it has been hypothesized to be accompanied by a distinctive (re-)organization of the way task-related regions interact among themselves [1]. Here we examined whether professional racers would show distinctive patterns of task-related functional brain regional correlations as compared to naive drivers and whether such distinctive networks would be engaged even for simple tasks that do not require any particular skill. That is, we expect the quantitatively different brain response observed in 'expert' to imply an underlying qualitative modification in brain functional organization.

Methods:

We used fMRI (GE Signa 1.5T) to examine neural activity in 11 professional (mean age±s.d.=24±4 yrs) and 11 naïve (28±4 yrs) driver right-handed healthy males in a 6-run block design study including two randomly-alternated tasks: a Go/NoGo task (starting grid lights: SL), and a multiple-target pursuit task (billiard: BL). Data were analyzed with the AFNI Package [4], using an approach based on a combination of bivariate and multivariate Granger Causality (b/mGC) analyses [5]. First, we identified a subset of 'core' regions activated in both naive and professional drivers by a conjunction activation map (logical AND, uncorrected $p<10^{-5}$, k=100μL). Five-mm radius spheres were centered on across-group activation peaks, and averaged timeseries were calculated within each sphere. A ROI-to-whole-brain and a whole-brain-to-ROI bGC analysis (3dGC.R [2]) for each task and subject were performed (lag order=1). Then, we computed a professional vs. naive drivers contrast for each ROI and task, using path coefficients and t-statistics from single subject results, with a mixed-effect meta-analysis approach (3dMEMA [3]). Statistical contrast maps obtained for core ROIs were converted to Z-score to identify two sets of 'differential' ROIs. These were defined as 5-mm radius spheres centered in the contrast Z-values peaks (Z=4.5, k>200, in SL task; Z=5.5, k>400, in BL task). Finally, we included both core and differential ROIs in a mGC analysis (1dGC.R [2]) and computed a group comparison for each task.

Results:

Task-related core regions included: supplementary motor area, cerebellum, bilateral insula and inferior occipital cortex, in SL; right dorsal premotor cortex, bilateral middle temporal complex and posterior intraparietal sulcus in BL task. bGC analysis revealed significant group differences in how these regions interact with other brain areas, thus defining the differential ROIs included in the subsequent mGC analysis: bilateral striatum and left anterior cingulate cortex, for SL; supplementary motor area, bilateral anterior inferior parietal lobule, right superior parietal lobule, cuneus, precentral gyrus and middle frontal gyrus for BL. Results from mGC analysis, consistent with that of bGC, showed that professional drivers had stronger correlations among areas of the core networks, while in naive drivers greater interactions between core and differential regions were prevalent (fig. 1-2).

Conclusions:

During visuomotor tasks reduced volumes of brain activation in professional racers were associated with both reorganized brain networks and reinforced correlations among task-related areas. As expected, these neural differences between the two groups were present during tasks that do not require any exceptional skill, as shown by the absence of any difference in task performance. These findings suggest that neural efficiency may be a matter of 'quality' of brain recruitment rather than 'quantity'.

Figure 1 – Starting Grid Task

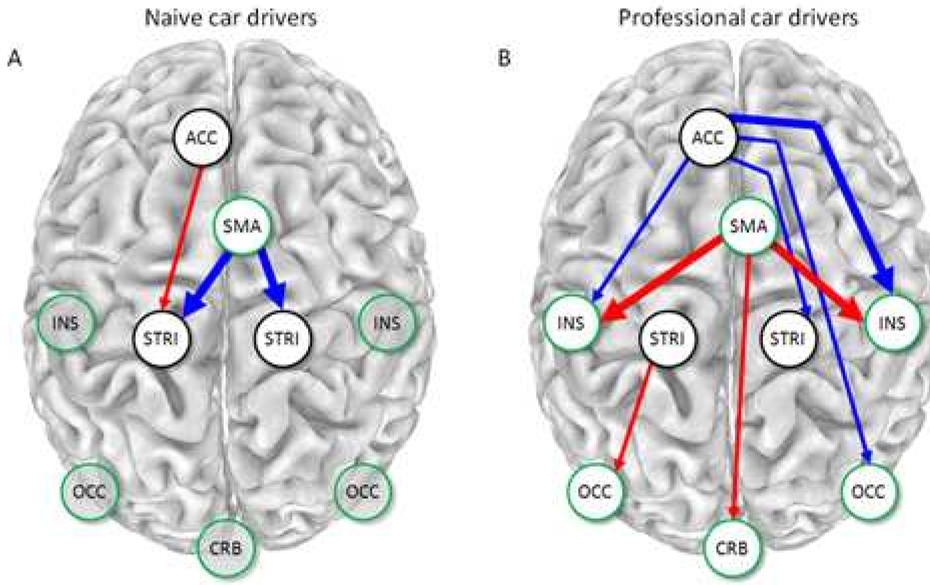

Figure 1. Between group comparisons from path coefficients of multivariate Granger Causality analysis during the starting grid task. Red and blue arrows respectively indicate significantly greater activation and inhibition of target regions in the two groups (thin arrows = $p < 0.05$ uncorrected, broad arrows = $p < 0.01$ uncorrected). During the starting grid task, core ROIs (green) were: bilateral inferior occipital cortex (OCC), insula (INS), supplementary motor area (SMA) and cerebellum (CRB). Differential ROIs (black) were: bilateral striatum (STRI), and anterior cingulate cortex (ACC).

Figure 2 – Billiard Task

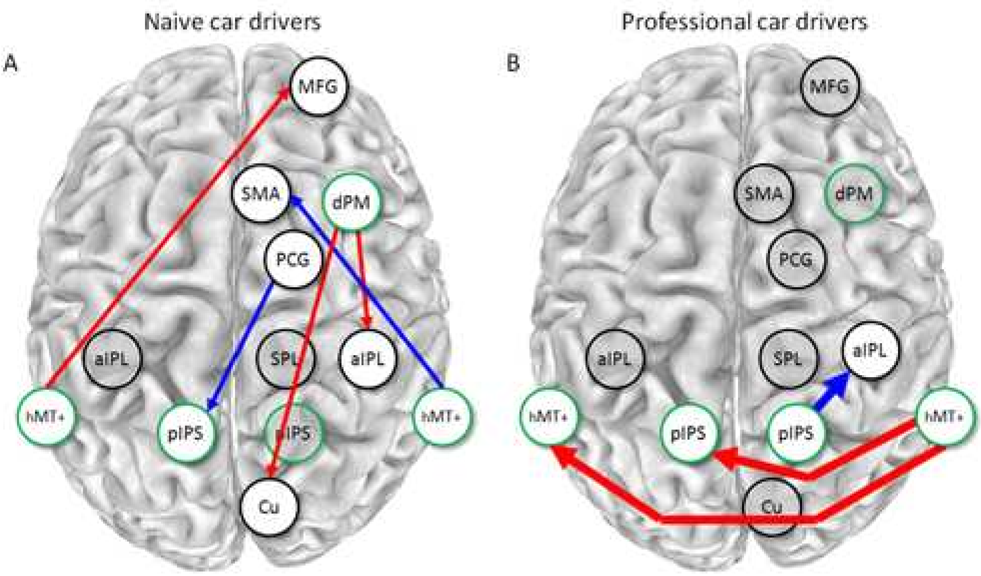

Figure 2. Between group comparisons from path coefficients of multivariate Granger Causality analysis during the billiard task. Red and blue arrows respectively indicate significantly greater activation and inhibition of target regions in the two groups (thin arrows = $p < 0.05$ uncorrected, broad arrows = $p < 0.01$ uncorrected). During the billiard task, core ROIs (green) were: bilateral human middle temporal complex (hMT+), posterior intraparietal sulcus (pIPS) and right dorsal premotor cortex (dPM). Differential ROIs (black) were: bilateral anterior inferior parietal lobule (aIPL), right superior parietal lobule (SPL), cuneus (Cu), precentral gyrus (PCG), middle frontal gyrus (MFG) and supplementary motor area (SMA).

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