Prefrontal networking during mental arithmetic

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We report the results of an event-related fMRI study of mental multiplication and estimation using the 3D BOLD related pulse sequence. Our focus in this poster is the prominent flocation activations seen. Numerous anatomically neighboring foci within the cingulates and the dorso-lateral prefrontal cortex shared their specific, parametric signal time courses. We hypothesize that spatially unique, transient functional connectivities are established by multivariate subpatterns recruited intermittently during mental calculation.

Introduction

Mathematical calculation is demanding and requires numerous elements of the brain. Stimulation and group high-lighted the crucial role of the parietal lobes in magnitude assessment and estimation for any cognitive task involved in calculation of any kind.1,2 However, not much is known about the specific role of the frontal lobes in mental arithmetic or on the functional interplay of frontal regions, other than that they are involved in the process of mental calculation.3,4

Particularly important in arithmetic problem solving is the coordination of attention and working memory, facilitating both long-term and short-term memory.6 To complete such a task, we chose an experimental design that maps comprehensive parts of the neural calculation system, and subsequently covers a multitude of cognitive aspects. The corresponding analysis method uses a set of parametric encoding variables that are correlated with the modulations of the BOLD signal time course.

Methods

Subjects: 36 healthy control subjects participated (24 women, one woman lost-handed, mean age 25±5, 30±4). All subjects were free of neurological deficits, dyslexia, dyslexia and attention deficit disorders.

Paradigm: An irregular, self-paced, and random event-related study design was implemented. Only single-digit operands were shown, e.g. 6 5. Subjects decided by a button press with one of the three middle fingers of their dominant hand how quickly to respond. If the subject hit the button (e.g., 23) was closest to the calculated, correct result (here: 20 or too small or too big). All solutions were given to 90% more or less than the correct value (±8). In 80% of the trials, a solution was provided for solutions found within ±2.5% proximity to the correct result; the two remaining offers were for solutions exceeding this threshold.

Operando pairs were excluded. The range of operand pairs was set from 1 34 up to 8 9. The order of operands was approximately randomized. Presentation times were: multiplication 2.55, BOLD 1.55, and DS (rest condition) until new cycle 1.05. Subjects were encouraged to respond as quickly as possible, resulting in irregular SOLs (4.6 4.6). They were exposed to two different cognitive tasks: (1) the maintenance of verbally encoded working memory for multiplication product solutions, when they were stored during the interval, before further processing;1 (2) a little later, task difficulty (equation 3) is the comparison of functional distance between cingulate and PPC and may also reflect response uncertainty, or conflict, or online monitoring of ‘competition between processes that conflict during task performance’ for that moment when subjects decide which button to press.5,12

We detected, furthered, a non-parametric modulated system of co-activation in the cingulate and lateral PPC that becomes stronger with higher BOLD signal numbers. We interpret this increase in the strength of the BOLD effect as a sign of ever increasing need for attention in algebraic exercises in which problem solving takes longer as the difficulty increases.

Emotion: Two inferior foci were detected in the neural corrosional (purple) and, of the effects, that sign responsible for those signal alterations, none were expected to exert influence in this parameter area, which is traditionally thought to process primarily affective components of cognition. We explain our observations, conceptually, as follows. First, the distance to the correct answer, in bits, has a higher correlation analysis (BFX). Bids in brainstorm renditions were thresholded at a voxel-based significance level of p ≤0.001.

Parametric courses: Calculation problems offer a variety of computable ratios between numerals and integer results such as operands, products, and differences: a × b = R, where R is the correct product and R is the displayed incorrect result. Three parametric vectors (regressors) were determined: (1) the numerical multiplication product (product size effect = PSE), (2) the relative numerical distance (distance effect = DE) between the correct (correct) and the offered incorrect (displayed) result; and (3) the distance difficulty (TDiff) based on the relative numerical distance from the incorrect (displayed) result, where PSE = −log to the base 2 (R/R), D = log to the base 2 (R/R) and TDiff = log to the base 2 (R/R).

Time courses: fMRI data were collected for both medium and high intensity time courses, depicted with a button press. Non-parametric activation foci with simple BOLD signal increases were detected in the highest foci of the median frontal lobes (blue). More likely some degree of memory was required for the second exposure and subsequently reduced burden and stress.

Motor: At the terminus of a calculation episode (onset of ‘attention’ in Fig. 2), a short delay (1 1.5 s) was introduced before the next button press and another BOLD signal increase is detected with a button press. Non-parametric activation foci with simple BOLD signal increases were detected in the highest foci of the median frontal lobes (blue). More likely some degree of memory was required for the second exposure and subsequently reduced burden and stress.

Results and Discussion

Numerous activation foci were detected in the anterior cingulate gyrus and prefrontal cortices (PFC) bilaterally, bonding many foci in the remaining brain areas. In summary, a series of multivariate foci were detected in the single sample fMRI study that are separable with regard to their anatomical location, episode occurrence within a cognitive task, and parametric signal properties that depend on the numerical mnemonic burden in each given mathematical exercise. We also found a series of large, in parts redundant activations in the lateral PPC that appeared to be functionally connected to the median foci, that in turn occurred at the same time (in identical BOLD bins), and shared highly specific patterns of signal time course modulation (see equations c) and c). Such modulations can be seen as a result of the time signatures of underlying multivariate subpatterns recruited during calculation exercises and apply a functional connective subpattern that can be extracted from the BOLD signal. In the last few years, imaging studies have revealed greater transparency in the functional organization of the anterior cingulate cortex3,6,7,8, which appears to be parsely through to three regions: an attentional control division and an interface with motor output control.9 We will now relate such evidence with our experimental results.

Cognition: In the current study, only foci in the cognitive division of the anterior cingulate revealed functional connectivity with the lateral PPC, which is sug-