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NEURAL CORRELATES OF CREATIVE INTELLIGENCE: AN FMRI STUDY OF FLUID ANALOGIES

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AIM OF STUDY

To identify neural correlates of creative fluid analogy-making

Introduction

Following William James "A native talent for perceiving analogies is … the leading fact in genius of every order" many commentators have argued that the essence of intelligent behaviour lies in making creative metaphors or fluid analogies. In other words, all human reasoning, including logical inference, is essentially analogical. Making an analogy is clearly rooted in perceptual experience; however it goes beyond perception in employing relationships. Creatively intelligent analogy-making is necessary for success in a wide range of endeavours, including pattern recognition, composition of musical variations, producing and appreciating humour, translation between languages, poetry, and much of everyday speech. That is, analogic reasoning, in particular analogy-making, is the cognitive-behavioural underpinning of intelligence, whether operationalised as a unitary construct 'g', or in a multi-componential manner which is popular in education, or in a creative sense as apparent with intellectual insight and original explanation.

Subjects

12 right-handed volunteers participated in the fMRI study (4 M, 8 F; age range 18 to 54 years). Subject IQ estimates were obtained from scores on the National Adult Reading Test (NART) 2nd Edition (range 108-128).

Experimental design

The criterion stimuli consisted of 30 fluid letter-string items selected from 80 *Copycat* items [1]. For each stimulus item, four choices for completion were selected from the most popular open-ended responses to that item by two classes of secondary school students [2]. Example:

if **abc → abd** *then* **pqqrrr → ?**

Plausible responses include **pqqrrd**, **pqqrrs**, **pqqsss** and **pqqssss**. Each choice was rated (non-parametric scale 1-4) for analogical depth on the number of transformation operations required to get from the prompt to that choice.

To control for non-cognitive aspects of the task, such as visual processing, eye movements and motor activity, baseline (control) stimuli consisting of 25 perfect-match letter-string items, e.g., **abc → abc**, **tsr → ?** (response **tsr)** were randomly interspersed throughout the criterion set.

The stimuli were presented in a self-paced event-related design, with responses recorded on a four-button box, using digits 2-5 of the right hand. Subjects were asked to fixate on a cross between stimuli presentations.

Image acquisition and data analysis

Functional and structural MRI images were acquired on a Varian/Siemens 3T system. For the functional data series, a variable number of T2* weighted EPI volumes (range 249-812 vols) were acquired. Each volume consisted of 24 continuous axial slices with an in-plane resolution of 3x4mm and thickness of 5mm, covering the whole brain (TR=3s, 64x64 Matrix, FOV 192x256 mm, TE=30ms, Flip angle 85º).

Analysis of the fMRI data was carried out using FEAT v5.1 [3] with MCFLIRT motion correction, spatial smoothing using a Gaussian kernel of FWHM 5mm; mean based intensity normalisation of all volumes by the same factor and nonlinear highpass temporal filtering (Gaussian-weighted LSF straight line fitting), t = 50s. Statistical analysis was carried out using FILM [4] by fitting a 2-event model GLM, where each event was convolved with the event reaction time. The 2 covariates of interest were: analogy strings and control strings. The data were collapsed across subjects' responses. Higher-level mixed-effects group analysis was carried out using FLAME (FMRIB's Local Analysis of Mixed Effects) [3].

Results

Reaction times for the analogy-string events (median RT=22.1s) were significantly longer (paired t-test p = 0.002) compared to control events (median RT=7.5s). Of the 360 (12 x 30) criterion item responses, 45% of responses were made at the maximum analogical depth rating, 43% were made at some intermediate rating, and 12% were made at the minimum depth rating. There was notable inter-subject variance in depth responses.

Figure 1 shows the network of areas activated comparing analogy strings to controls. Anterior bilateral frontal cortical areas overlap with regions reported in previous studies of general intelligence and analogic reasoning [5-8]. Bilateral posterior activations were also observed, attributable to stimulus-specific considerations.

Figure 1. Mixed effects model group map of [analogy string – control string]. Thresholded at Z > 2.3, cluster significance p < 0.01

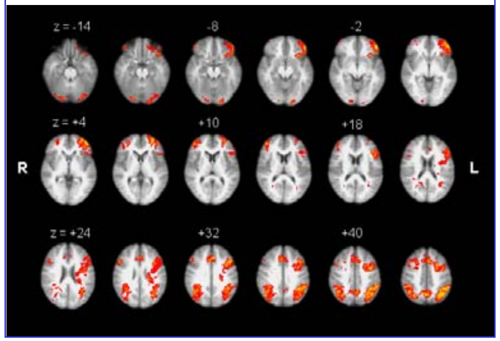


Table 1: Anatomical description, location and Z score of activated clusters.

Region	Hemisphere	BA	Tal x	Tal y	Tal z	Z score
Lingual Gyrus	L	18	-16	-92	-8	3.7
Lingual Gyrus	R	18	20	-86	-10	3.7
IFG ventral (vlPFC)	L	47/12	-50	44	-10	4.7
IFG ventral (vlPFC)	R	47/12	48	48	-12	4.0
MFG (vlPFC)	L	47/10	-44	50	2	4.8
MFG (vlPFC)	R	47/10	48	46	8	4.2
IFG (dlPFC)	L	44/45	-46	18	14	4.3
IFG (dlPFC)	R	45/46	52	22	20	3.6
MFG (dlPFC)	L	9	-50	26	32	4.2
Anterior Cingulate	L	32	-4	24	40	4.8
Anterior Cingulate	R	32	6	22	42	3.0
SFG	L	8	-26	22	44	4.2
SFG	R	8	-30	24	44	4.1
Precuneus	L/R	7	0	-60	48	4.3
Inferior Parietal Lobule	L	40/7	-34	-62	44	5.0
Inferior Parietal Lobule	R	40/7	30	-60	44	4.8

ROI Analysis and Variation with IQ

A second level analysis of the data, covarying for subject IQ, revealed a significant cluster of 41 voxels centred at Talairach coordinates (-38, 32, 20) corresponding to BA 46/9, left middle/superior frontal gyrus. This cluster was used to define a region of interest (ROI) in individual subject space for further investigation.

Figure 2: ROI defined by group map showing frontal cluster that covaries with NART score. Thresholded at Z > 1.8, cluster significance p < 0.01.

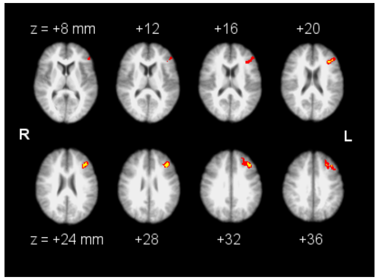


Figure 3: Variation of %BOLD signal change between task conditions in the IQ-defined ROI.

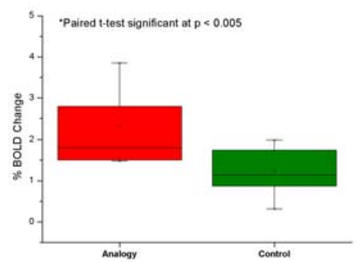
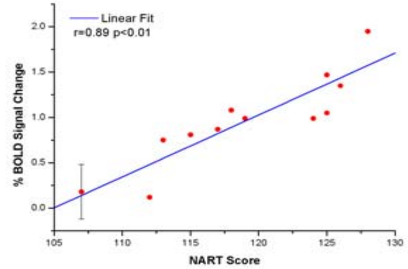


Figure 4: Variation across the sample group of the BOLD signal change with NART score in the IQ-defined ROI



The cluster shows activity linearly related to subject NART score. Interestingly, Rypma et al [4] have shown activity in an almost identical area in a working memory task involving an array of letters. Gray et al [7] also found a similar relationship in BA 46/45 between % BOLD change and general intelligence as measured by the Raven's Matrices.

CONCLUSIONS

- This experiment demonstrates the viability of using a multiple-plausibility self-paced fMRI design to investigate neural correlates of fluid letter string analogy-making.
- We found patterns of frontal activations which were similar to those activation patterns found in previous studies into the neural correlates of general high intelligence [6,7], and analogical and deductive reasoning in particular [8,9].
- A ROI analysis in left BA 46/9 shows a significant linear relationship between IQ and %BOLD change on the fluid analogy task, consistent with previous interpretations of this area as mediating executive functioning under high working memory load [4].
- This result supports the pivotal role of analogising in intelligent behaviour, especially intelligent behaviour incorporating elements of creativity through the adaptive reorganisation and restructuring of novel information.

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