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Neuroimaging study of numbers, Chinese words, and English words reading in brain

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ABSTRACT

Chemical engineering Professors in Taiwan commonly deliver lectures in mixed Chinese and English words accompanied with numbers. To the authors' best knowledge, no studies have explored how the brain of the same individual processes reading of numbers, Chinese words and English words. This work investigated brain activity by applying functional magnetic resonance imaging (fMRI) for selected University students. The activation patterns in brains revealed distinct behavior, which can be roughly divided into two categories. The Group A subjects focused on language words reading; conversely, showed little interest to numbers with no intention for further comprehension. The Group B subjects paid high attention to numbers, and activate numerous brain areas to interpret the therein hidden meanings. Meanwhile, these subjects largely ignored the Chinese or English words in reading. The two groups of subjects should be subjected to different curriculums in chemical engineering education.

1. Introduction

Functional brain imaging and mapping have been utilized to investigate which and how brain regions are activated in response to different environmental stimuli. Kobayashi *et al.* (2006) investigated whether the human brain has a center for predicting the behavior of others. Crinion *et al.* (2006) analyzed how a bilingual brain is activated to identify and control the language in use. Sugihara *et al.* (2006) investigated whether humans have a universal center in the brain for writing. Certain brain regions, such as medial prefrontal cortex (mPFC) and temporo-parietal junction (TPJ), were significantly correlated with the activity of the human "mind" (Decety and Grezes, 2006; Gusnard *et al.*, 2001). Schwarzlose *et al.* (2005) and Tsao *et al.* (2006) determined that the fusiform face area (FFA) in the fusiform gyrus of the brain is strongly associated with face recognition.

Learning, which consists of vision, comprehension, reasoning, and information storage, is a dynamic brain process. Brain imaging research into mathematic implementation is still limited (Tang *et al.*, 2006).

Wang *et al.* (2008a) revealed that the message of partial differential equation, received by the primary visual cortex (V1) and activation of the lingual gyrus and fusiform gyrus, would be sent through the dorsal stream (the left superior parietal lobule, Brodmann area (BA) 7 and middle frontal gyrus, BA 6) to the superior frontal gyrus (BA 8 and 9), Broca area (BA 45). Further processing was achieved by sending message from Broca area to the Wernicke's area (BA 40) via the arcuate fasciculus and to the inferior and middle temporal gyrus (BA 20 and 21). Wang *et al.* (2008a) showed that the brain identifies the partial differential equation by its shape and processes the message as a syllabary. Comprehension and interpretation may be conducted at the Wernicke's area.

Wang *et al.* (2008b) revealed that reading plus finger writing did not change the message pathway, but stimulate the BA 6, 7, 9, and 40. Finger writing activated BA 1–3, probably hence strongly stimulating the dorsal pathway via BA 7 and then 6. Conversely, writing had no significant effects on left middle frontal gyrus or BA 44 and 45. Restated, finger writing has no effect on abstract meaning comprehension. Learning with writing practice should be beneficial to student for summarizing and comprehending information delivered in chemical engineering classrooms. However, writing could not significantly assist equation interpretation.

Chemical engineering education in Taiwan's classrooms is commonly conducted in mixed languages: Chinese and English accompanied with numerous numbers. To the authors' best knowledge, no studies have explored how the brain of the same individual processes reading of numbers, Chinese words and English words. This work investigates brain activity by applying functional magnetic resonance imaging (fMRI) on the activated areas of brain and along the stream the read message is sent on in

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the brain. The ultimate goal of this series study is to provide information on ''what works'' in chemical engineering classrooms.

2. Materials and methods

2.1. Subjects and tasks

Twelve right-handed university students aged 21–26 years participated in this study. All subjects were native Chinese speakers with no history of neurological disorders, and had normal or corrected vision. Written consent was obtained from all subjects.

Three block designs were utilized: (1) reading a series of numbers silently; (2) reading a series of Chinese words silently; (3) reading a series of English words silently. Each fMRI test lasted for 1 h.

2.2. Stimuli and MRI procedures

The three tasks were blocked in a random order and interleaved with the fixation condition in each experimental session. For each block test, two scanning periods were utilized: (1) when one of the three tasks was performed and (2) a rest period (baseline). Each block continued for 600 s, and a task and a rest period were repeated 10 times. A PC controlled the stimulus presentation. The stimuli were projected via an LCD projector onto a screen located at the subject's feet. Each subject could clearly see the screen at a viewing distance of roughly 2 m.

A 3T GE Sigma LX system with a standard head coil was used for acquiring echo planar imaging (EPI). A gradient-echo EPI sequence (TR = 2 s; TE = 25 s; flip angle = 90°; FOV = 24 cm $\times$ 24 cm; 64 $\times$ 64 matrix; in-plane resolution, 3.75 mm $\times$ 3.75 mm) was adopted to assess the T2*-weighted time-series images depicting blood oxygenation level-dependent (BOLD) contrast. Thirty-five axial contiguous 4-mm-thick slices covering the whole brain were collected. Each block for each condition lasted for 15 volumes (the instruction for 2 s = 1 vol, and each task period was 30 s = 15 vol). Here, 150 volumes were obtained in a single session. Structural high-resolution T1 images were also collected prior to experimental sessions (TR = 10.212; TE = 4.856; flip angle = 90°; FOV = 24 cm $\times$ 24 cm; 521 $\times$ 512 matrix; 172 slices; 0.9 mm thick; no gap).

2.3. Imaging data analysis

The Statistical Parametric Mapping (SPM2) (Wellcome Department of Cognitive Neurology, London), running under Matlab 7.0.0 (Mathworks, Sherbon, MA, USA) analyzed the data. To minimize T1 relaxation artifacts, the first four scans were excluded from the analysis. All volumes were realigned to the first volume with 4th-degree B-spline interpolation and were resliced. Individual T1 image was coregistered to a mean EPI image. Individual T1 images were normalized to the Montreal Neurological Institute (MNI) T1 template (2 mm $\times$ 2 mm $\times$ 2 mm) of SPM2 to derive the transformation parameters. Individual T1 images were resampled into 1 mm $\times$ 1 mm $\times$ 1 mm voxels, and the EPI images were resampled into 3 mm $\times$ 3 mm $\times$ 3 mm voxels with 4th-degree B-spline interpolation. A Gaussian kernel of an 8-mm isotropic full wave at half-maximum smoothed the acquired EPI images.

The functional data were evaluated as a block design using a general linear model approach. Each subject's dataset consisted of 300 volumes, which were collapsed into task and rest images with SPM's canonical hemodynamic response function (HRF) with a time derivative. High-pass temporal filtering with a cut-off of 128 s was applied, and serial autocorrelations were modeled with an AR(1) model in SPM2.

3. Results and discussion

As discussed later, the activation areas in brains for all subjects can be categorized into two groups. Group A is composed of subjects with much stronger activation in certain brain areas when reading Chinese or English words than numbers. Group B comprised of subjects with brain activation much stronger when reading numbers compared with reading Chinese or English words.

3.1. Number reading

3.1.1. Group A

Fig. 1a and Table 1a present the typical brain activation patterns for Group A during number reading *versus* fixation ($p < 0.001$, uncorrected). 19 activation areas were identified. The activation area 1 is composed of 349 voxels, peaking at [32,−90,26], with detailed sub-areas as cuneus [right (49%)], middle occipital gyrus [right (24.1%)], superior occipital gyrus [right (14.6%)], middle temporal gyrus [(right (2.0%)] and sub-gyrus [right (5.4%)]. This activation area mainly encompassed the BA 18 [right (6.3%)] and BA 19 [right (31.0%)]. Restated, this area strongly corresponded to vision activity. Area 5 also shows similar vision activity.

The activation area 2 is composed of 183 voxels, peaking at [16,70,8], with detailed sub-areas as superior frontal gyrus [left (1.6%) and right (39.4%)] and middle frontal gyrus [left (7.7%) and right (7.7%)]. This activation area encompassed the BA 10 [left (1.1%) and right (36.1%)]. Activated areas 6, 7, 12, 13 and 19 revealed similar characters.

The Wernicke's area [left (22 voxels) and right (14 voxels)] were activated in a finite magnitude. A finite firing of BA 37 [right (10 voxels)] was noted for Group A subjects.

3.1.2. Group B

Fig. 1b and Table 1b present the typical brain activation patterns for Group B during number reading *versus* fixation ($p < 0.001$, uncorrected). 24 activation areas were identified. The activation area 1 is composed of 693 voxels, peaking at [58,4,38], with detailed sub-areas as precentral gyrus [right (56.1%)], inferior frontal gyrus [right (3.6%)] and middle frontal gyrus [right (39.3%)]. This activation area encompassed the BA 6 [right (46.9%)] and BA 9 [right (4.3%)].

The activation area 2 is composed of 574 voxels, peaking at [−32,−58,24], with detailed sub-areas as fusiform gyrus [left (12.4%)], inferior occipital gyrus [left (5.2%)] and middle occipital gyrus [left (7.5%)]. This activation area encompassed the BA 37 [left (1.1%)] with other vision areas. Restated, this area corresponded to visual message collection and memory acquisition. Similarly, active areas 3, 5, 6, 11, and 15–19 correspond to the vision areas.

The activation area 7 is composed of 299 voxels, peaking at [46,−52,58], with detailed sub-areas as interior parietal lobule [right (74.3%)] and superior parietal lobule [right (8%)]. This activation area incorporated the BA 7 [right (5.0%)] and BA 40 [right (43.1%)]. The activation area 23 also revealed this activity.

The activation area 13 is composed of 75 voxels, peaking at [50,38,26], with detailed sub-areas as middle frontal gyrus [right (100%)]. This activation area closely corresponded to the Borca's area for word semantic information. The activation area 20 was for left inferior frontal gyrus (L-IFG) which is an area for information integration. The Wernicke's area [right (129 voxels)] were activated. The BA 37 [left (47 voxels) and right (6 voxels)] were stimulated for Group B subjects.

3.2. Chinese word reading

3.2.1. Group A

Fig. 2a and Table 2a present the typical brain activation patterns for Group A during Chinese words reading *versus* fixation