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An EEG Case Study of Arithmetical Reasoning by Four Individuals Varying in Imagery and Mathematical Ability: Implications for Mathematics Education

Mark Rousell, Di Catherwood, and Graham Edgar

Abstract**—**The main issue of interest here is whether individuals who differ in arithmetical reasoning ability and levels of imagery ability display different brain activity during the conduct of mental arithmetical reasoning tasks. This was a case study of four participants who represented four extreme combinations of Maths – Imagery abilities: ie., low-low, high-high, high-low, low-high respectively. As the Ps performed a series of 60 arithmetical reasoning tasks, 128-channel EEG recordings were taken and the pre-response interval subsequently analysed using EGI Geosource^{TM} software. The P who was high in both imagery and maths ability showed peak activity prior to response in BA7 (superior parietal cortex) but other Ps did not show peak activity in this region. The results are considered in terms of the diverse routes that may be employed by individuals during the conduct of arithmetical reasoning tasks and the possible implications of this for mathematics education.

Keywords**—**Arithmetic, imagery, EEG, education.

I. Introduction

THE requirement to reason arithmetically in day-to-day life may cause concern for some individuals, not only for students in the classroom, but also in other situations, e.g., working out shopping bills [1], [2]. Investigation into individual differences in mental arithmetic capacity is thus an important social issue as well as a theoretical one and may be essential for designing effective teaching approaches and aids.

There are many approaches to teaching arithmetic but it is also the case that mental arithmetical problems are solved in numerous ways [3] and there may well be individual tendencies towards one approach or another even prior to or without formal tuition [4], [5]. One factor that may play a key role in arithmetical function is the capacity to use visual imagery. The ability to represent number and numerical calculations in a visual way may support core cognitive operations such as working memory during arithmetical tasks [6]. The current investigation represents a preliminary EEG case study of individuals who vary in imagery and arithmetical ability. The aim here is to determine whether individuals who differ in these factors display different patterns of brain activity during arithmetical reasoning tasks. EEG analysis has begun to be usefully applied to studies of mental arithmetic [7]. Further understanding of brain activity underlying arithmetical reasoning may enhance the development of educational strategies in regard to arithmetic education.

All authors are with the Centre for Research in Applied, Cognition, Knowledge, Learning and Emotion (CRACKLE) in the School of Natural and Social Sciences at the University of Gloucestershire, Cheltenham, GL50 4AZ, United Kingdom (corresponding author is Dr. Di Catherwood phone: +44 1242 714808; fax: +441386553687 ; e-mail: dcatherwood@glos.ac.uk).

II. Method

A. Design

The experiment involved a case study of brain activity during mental arithmetical reasoning by four participants representative of different combinations of maths and imagery abilities, i.e., low-low, high-high, high-low, low-high respectively. As Ps performed the maths tasks, EEG recordings were taken and subsequently analysed using Geosource^{TM} software, with amplitude of activity in the maximum intensity regions-of-interest (ROI) prior to making a response serving as the dependent variable.

B. Participants

Participants were four female university students and staff aged from 18-59 (M = 31years, SD = 19.37).

C. Materials and Apparatus

A series of on-screen addition problems were administered via E-prime^{TM} software. Similar problems were used for classifying the participants into Maths ability groups and for the EEG task. Imagery ability was assessed with a revised version of the VVIQ2 [8], [9], a valid and reliable measure of visual image vividness linked to cortical activity in prior work [10] - [13].

For the EEG task, 60 addition problems were randomly presented and involved two digit and three digit problems, e.g., 54 + 21 and 474 + 373 respectively. The presented sums simultaneously displayed an answer and the participant was required to judge this as correct or not. The task involved controls for incomplete working and/or guesswork. 128 channel dense-array EEG data was recorded via EGI‘s Geodesic Sensor Net (HydroCel GSN)^{TM} and connected to a high impedance NetAmps™ amplifier (Electrical Geodesics Inc., Eugene, Oregon).

D. Procedure

As Ps performed the task, EEG activity was recorded. EEG raw data files were processed through NetStation software. Source analysis was conducted through GeoSource with the

MNLS (Minimum Norm Least Squares) and standardized Low Resolution Electrical Tomography (sLORETA) algorithms, the latter having zero localization error in noise-free simulations [14] and widely used in studies of cognitive and perceptual processing [15]. sLORETA is an improvement on its predecessor LORETA that was nevertheless validated for use in similar tasks to the current one [16]. The visualization of brain activity used a finite difference method (FDM) realistic head model and the Montreal Neurological Institutes (MNI) typical head image as a template. The approach enables both location and magnitude of brain activity to be recorded and analysed to a degree of accuracy adequate for identifying general brain regions active in the tasks of the current type.

Data were segmented into 1000ms stimulus intervals, filtered and averaged, average-referenced, with automatic ocular artifact correction applied and bad channels removed. The following data reflect regions of peak brain activity 500ms *prior to* actual response. This was designed to reflect ROI relevant to the cognitive processing of the arithmetic problem

III. Results

The data reveal different patterns of activity for the four Participants. Of course many brain regions were active during the various task intervals, but as a first examination of the data, the regions of peak or maximal activity during the interval preceding response were examined. The following brain regions (denoted by Brodmann areas: BA) were maximally active for each of the four Ps (see Table I).

TABLE I
Brain Regions Showing Peak Activity during Pre-Response Interval for Each of the Four Participants

P1 (low maths-low imagery)	P2 (high maths-high imagery)	P3 (high maths-low imagery)	P4 (low maths-high imagery)
BA 18 lingual gyrus (occipital lobe)	BA7 superior parietal lobule/ precuneus (parietal lobe)	BA 18 lingual gyrus (occipital lobe)	BA11 middle frontal gyrus (frontal lobe)

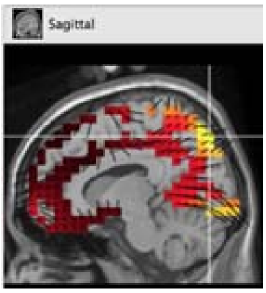

Fig. 1 Sagittal View Representation of Brain Activity for P2 in Pre-Response Interval: Cross-Hairs Indicate Maximal Activity in BA 7

IV. Conclusion

This current research indicates that participants engaged separate approaches and neurological pathways in the navigation of the mental arithmetical tasks and hence this finding supports previous evidence in this regard [17].

P2 (high-high) is of particular interest and displayed consistent peak activity in the posterior part of the superior parietal lobe, namely BA7 (superior parietal lobule/precuneus), throughout the task (see Fig. 1). This general area is involved in visuospatial cognition and imagery and also symbolic numerical processing [6], [18] - [20]. P2'S peak brain activity is consistent with activation of brain regions expected during both mental arithmetical tasks and visuo-spatial imagery. The other high-maths participant did not show such localisation of peak activity in BA7 but engaged high-level visual pathways (BA18) as did P1 who was representative of low maths-low imagery ability. The remaining participant was high-imagery but nevertheless did not show high use of BA7 in the maths task. It would thus seem that neither high maths ability per se nor high imagery ability per se need necessarily predispose an individual to using visuo-spatial imagery regions during the performance of arithmetical tasks.

These conclusions are by necessity highly speculative given the small samples involved, but nevertheless the results offer a valuable first step towards identifying the diverse brain activity patterns that may reflect different strategies in performing mental arithmetical tasks. There are clear potential implications here for arithmetical education. It may prove invaluable to determine how individuals call on different brain pathways to perform arithmetical tasks. individuals who are high in imagery and maths ability may benefit from quite different approaches to those who are low in both for example. Design of educational approaches for arithmetic education may thus benefit from further study of these individual brain patterns.

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