Informatics 1 Cognitive Science – Tutorial 6 Solutions

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Week 7

This tutorial has two aims. First, you will learn to read and understand a research paper in cognitive neuroscience. Research papers tend to be technical and precise, and sometimes hard to follow if you are not an expert in the relevant field. The paper chosen here is no exception, but the background you have from the lectures will help you to get the main points:

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. Proceedings of the National Academy of Sciences, 97(8), 4398-4403. `https://www.pnas.org/content/97/8/4398.short`

As a neuroimaging study it contains some technical details about the experiments (the scanning parameters for instance) that are not really relevant for understanding the main results, but important for experts to see the study was technically solid. Such details can therefore be ignored.
Second, we will ask how much we can learn about the brain by looking just at anatomy, without measuring activity. The paper describes an analysis that Eleanor Maguire[1] carried out of structural brain scans from London taxi drivers. These taxi drivers are special (in many ways, but here we focus on their navigation skills): to obtain a license, they have to "Learn the Knowledge of London"[2], which requires them to know 320 routes within the six mile radius of Charing Cross. This not only means memorising around 25,000 streets, but also how they are connected.

Some potentially unfamiliar terms explained:

Voxel-based morphometry, VBM A method for analysing MRI scans where each scan is first aligned to an average brain. This allows identification of different brain areas.

Anterior/posterior hippocampus Anterior is an anatomical term that refers to the front, and posterior to the back. This distinction is made here to describe different parts of the hippocampus. Figure 2 illustrates this.

ANOVA Stands for Analysis of Variance, a type of statistical hypothesis testing based on comparing mean values between groups. Used here to find potential confounders that can explain the observed differences.

Sagittal section A section (e.g. a 2D scan) along the plane that divides the body in left and right.

Coronal section A section that divides the body in front and back.

Z score Number of standard deviations a measured value is away from the mean.

[1] `https://en.wikipedia.org/wiki/Eleanor_Maguire`
[2] `https://tfl.gov.uk/info-for/taxis-and-private-hire/licensing/learn-the-knowledge-of-london`

Questions

1. Research often starts with a hypothesis that determines the design of the experiments. What was the hypothesis that led to the experiment described in this paper?
   Solution: This is explained in the introduction. The hippocampus (a brain structure with a shape of a seahorse, hence the name) has been implicated in spatial memory and navigation in many studies in humans and animals. In different animal species, the size of the hippocampus (relative to other brain structures) can be related to behaviours requiring spatial skills. However, such differences may be primarily genetically determined. *Here the authors hypothesise that the size of the hippocampus is different in people who use spatial navigation skills more extensively than an average person*; in other words that the size of an entire brain structure is not fixed, but can adapt to changing demands.

2. Describe the experiment. What information is given about the participants, and why is this important?
   Solution:

   - Study participants were 16 right-handed male licensed London taxi drivers of varying age. All had been licensed for more than 1.5. All had healthy general medical, neurological, and psychiatric profiles.
   - The underlined factors are all attempts to remove possible extra confounders that could influence the result: gender, handedness, general health. It is also important that this information is provided as it is essential for replication of the study.
   - A structural MRI scan was performed for each participant. The voxel size was 1x1x1.5 mm^3.
   - For comparison, the scans of 50 non-taxi-drivers (with similar age profile, right handed, male, healthy) scanned previously were used.

3. While the details of the methods to analyse the brain scans will only be familiar to experts, the authors chose two different methods to measure the size of the hippocampus. The present results from both methods. Why?
   Solution: One is based on aligning brain areas (Voxel-based morphometry, VBM), while the other was counting pixels directly (then normalised by intracranial volume). We can expect that neither method is perfect, as brains differ and the anatomy in the scans can be somewhat ambiguous. Therefore, using two methods that measure not the same quantities gives more confidence in results.

4. Now describe the results of the study, using Figures 1-3.
   Solution:

   - Figure 1: Using VBM, on average the posterior hippocampus in taxi drivers is larger (b), and the anterior hippocampus is large in controls (c). True in both hemispheres. Importantly, it's the grey matter that differs, so these structures likely contain more neurons (not connections).
   - Figure 2: Summarises the pixel counting data in bar charts, confirms result in Figure 1. Could point out that it would have been easy to show each participant as a single dot here (swarmplot), a bar char chart often hides aspects of the data.
   - Figure 3: Tests additional hypothesis that there is a correlation between volume change and time as taxi driver. Shows opposing tends for anterior and posterior hippocampus.
   - Taken together: Posterior hippocampus is larger in taxi drivers, and the anterior hippocampus is smaller in taxi drivers. (It's a small effect, but has been replicated since by others such as Hugo Spiers)

5. Discuss what this study tells us about cognitive abilities and the brain. What question would you ask next? Can you suggest an experiment to address it?
Solution:

- Consistent with functional specialisation of brain areas. The posterior hippocampus has long been associated with spatial navigation (Alzheimer's affects the hippocampus at an early stage, and loss of spatial awareness is a common symptom). More generally, the hippocampus is seen as the site of cognitive maps.
- Relative size of brain structures gives is, to some extent, indeed related to cognitive ability. Example from the lecture is the elephant, with a much larger brain than ours, but most neurons found in the cerebellum, a structure relevant for precise movement and timing.
- The brain can re-allocate resources where needed, different structures are not fixed. Motor homunculus was mentioned in the lectures, and learning skills can re-organise this to some extent.
- Open discussion. Emphasise scientific approach required for such experiments: statement of a hypothesis, experimental design, control for confounders, influence of analysis method especially when data is complex (e.g. neuroimaging data), caution with small effects. A famous example where this went very wrong are early experiments on social priming, which turn out to be mostly irreproducible.