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Research report

Knowing what and where: TMS evidence for the dual neural basis of geographical knowledge

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ABSTRACT

All animals acquire knowledge about the topography of their immediate environment through direct exploration. Uniquely, humans also acquire geographical knowledge indirectly through exposure to maps and verbal information, resulting in a rich database of global geographical knowledge. We used transcranial magnetic stimulation to investigate the structure and neural basis of this critical but poorly understood component of semantic knowledge. Participants completed tests of geographical knowledge that probed either information about spatial locations (e.g., France borders Spain) or non-spatial taxonomic information (e.g., France is a country). TMS applied to the anterior temporal lobe, a region that codes conceptual knowledge for words and objects, had a general disruptive effect on the geographical tasks. In contrast, stimulation of the intraparietal sulcus (IPS), a region involved in the coding of spatial and numerical information, had a highly selective effect on spatial geographical decisions but no effect on taxonomic judgements. Our results establish that geographical concepts lie at the intersection of two distinct neural representation systems, and provide insights into how the interaction of these systems shape our understanding of the world.

1. Introduction

There is a long history of studies investigating how humans and other animals learn about the topography of their environments through direct exploration and navigation. Much of this work has focused on the roles of the hippocampus and parahippocampal regions in topographical learning and in the representation of scenes and environments (Burgess, Maguire, & O'Keefe, 2002; Hafting, Fyhn, Molden, Moser, & Moser, 2005; Maguire et al., 1998; O'Keefe & Nadel, 1978). In addition to direct experience, however, humans also learn about locations indirectly through exposure to verbal and

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non-verbal materials (e.g., travel guides and maps). This learning contributes to a rich database of global geographical knowledge, on a much larger scale than could achieved through direct experience alone (Beatty, 1989; Friedman & Dewinstanley, 2006). This information is integral to a range of everyday situations, from planning journeys and holidays to identifying locations described in news reports. In addition to its relevance in everyday life, geographical knowledge is of considerable theoretical interest. Geographical concepts comprise both spatial (e.g., Spain borders Portugal) and non-spatial (Spain is a hot country) elements and thus offer a unique opportunity to investigate the interaction of the brain's semantic and spatial representation systems (Crutch & Warrington, 2003, 2010). Almost nothing is known, however, about the neural basis of geographical concepts.

In this study, we investigated the roles of the right intraparietal sulcus (IPS) and left anterior temporal lobe (ATL) in the representation of geographical knowledge. The ATL and IPS are major components in two distinct representational systems specialised for different types of knowledge. In recent years, the ATL has emerged as a key site for representation of semantic knowledge for the meanings of words (Binney, Embleton, Jefferies, Parker, & Lambon Ralph, 2010; Hoffman, Binney, & Lambon Ralph, 2015; Pobric, Jefferies, & Lambon Ralph, 2007), properties of objects (Pobric, Jefferies, & Lambon Ralph, 2010a; Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996) and the identities of people (Drane et al., 2013; Haxby, Hoffman, & Gobbini, 2000). The critical role of this region is illustrated clearly by the profound deterioration in these forms of knowledge observed in the syndrome of semantic dementia, a neurodegenerative disorder associated with ATL atrophy (Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000; Crutch & Warrington, 2006; Hodges & Patterson, 2007). In contrast, IPS is involved in numerical and spatial processing (Dehaene, Piazza, Pinel, & Cohen, 2003; Hubbard, Piazza, Pinel, & Dehaene, 2005; Mazard, Tzourio-Mazoyer, Crivello, Mazoyer, & Mellet, 2004) and, in particular, is thought to be the site of the “approximate number system” – a system involved in abstract representation of numerical magnitudes (Feigenson, Dehaene, & Spelke, 2004). It has been proposed that this region uses a common code to represent not only numerical quantities but also magnitudes in sensory domains, including physical size and distance, temporal duration and luminance (Cohen Kadosh, Lammertyn, & Izard, 2008; Hubbard et al., 2005; Walsh, 2003).

Typically, the functions of the ATL “semantic” system and the IPS “magnitude” system are highly dissociable. Patients with ATL damage, for example, exhibit preserved understanding of numerical magnitude (Cappelletti, Butterworth, & Kopelman, 2001; Cappelletti, Kopelman, Morton, & Butterworth, 2005; Crutch & Warrington, 2002; Diesfeldt, 1993; Jefferies, Patterson, Jones, Bateman, & Lambon Ralph, 2004) and are able to estimate quantities accurately (Julien, Thompson, Neary, & Snowden, 2010), despite severe deficits in knowledge for objects and words. Conversely, parietal damage is frequently associated with dyscalculia but relative preservation of verbal semantic knowledge (Dehaene & Cohen, 1997; Delazer, Karner, Zamarian, Donnemiller, & Benke, 2006; Kas et al., 2011). We predicted, however, that both systems would play important roles in the representation of geographical concepts. Much of our knowledge for locations is acquired through exposure to verbal sources of information hence, in common with other forms of verbal semantic knowledge (e.g., Binney et al., 2010), we predicted that the ATL would support this information. However, unlike most other verbal and object concepts, geographical concepts are strongly associated with a particular location in space and with fixed spatial relationships with other known locations. These relationships are integral to our understanding of them. For this reason, we predicted that parietal lobe regions involved in spatial representation would also make an important contribution to the representation of these concepts.

To test these hypotheses, we used repetitive transcranial magnetic stimulation (rTMS) to temporarily disrupt the function of either IPS or ATL in healthy participants. rTMS is commonly used to investigate the functions of specific cortical regions by inducing temporary neural disruption and observing the effects on cognitive processes of interest. This is often referred to as the “virtual lesion” technique (Walsh & Cowey, 2000). Previous rTMS investigations have implicated the ATL in semantic knowledge for words and objects (Pobric et al., 2007, 2010a) and IPS in the representation of numerical magnitudes (Dormal, Andres, & Pesenti, 2008; Gobel, Walsh, & Rushworth, 2001; Kadosh et al., 2007). Here, we investigated how disruption to these two areas affected spatial and non-spatial aspects of geographical knowledge.

2. Method

2.1. Participants

Eighteen right-handed participants took part (9 female; mean age = 25). All participants grew up and had spent the majority of their lives in the United Kingdom. All participants provided written consent after being screened for adverse effects of TMS. The experiment was approved by the local ethics committee. At the beginning of the study, participants were asked to rate, on a 7-point scale, their level of geographical knowledge of the UK and the rest of the world. The two ratings were averaged to give a measure of perceived geographical ability.

2.2. Tasks probing geographical knowledge

Participants completed two matching tasks probing different aspects of geographical knowledge (see Fig. 1). Each task consisted of 50 Global and 30 UK trials. The taxonomic task required participants to select which of two alternatives was the same type of location as the probe. On Global trials, participants were instructed that they would be presented with cities and countries from around the world and they were to match cities with cities and countries with countries. On UK trials, they were presented with cities and regions within the UK and instructed to match cities with cities and regions with regions. The proximity task required participants to select which of two alternatives was located the shortest distance from the probe. On proximity trials, all locations were taken from the same taxonomic category (e.g., all were cities).