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Review

Individual differences in cognitive style and strategy predict similarities in the patterns of brain activity between individuals

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ABSTRACT

Neuroimaging is being used increasingly to make inferences about an individual. Yet, those inferences are often confounded by the fact that topographical patterns of task-related brain activity can vary greatly from person to person. This study examined two factors that may contribute to the variability across individuals in a memory retrieval task: individual differences in cognitive style and individual differences in encoding strategy. Cognitive style was probed using a battery of assessments focused on the individual's tendency to visualize or verbalize written material. Encoding strategy was probed using a series of questions designed to assess typical strategies that an individual might utilize when trying to remember a list of words. Similarity in brain activity was assessed by cross-correlating individual *t*-statistic maps contrasting the BOLD response during retrieval to the BOLD response during fixation. Individual differences in cognitive style and encoding strategy accounted for a significant portion of the variance in similarity. This was true above and beyond individual differences in anatomy and memory performance. These results demonstrate the need for a multidimensional approach in the use of fMRI to make inferences about an individual.

Contents

Introduction

One of the goals of neuroergonomics is to use neuroscientific tools to understand the individual mind at work in a naturalistic

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environment (Parasuraman and Wilson, 2008). But the use of functional magnetic resonance imaging (fMRI) to make an inference about an individual is particularly challenging (see Parasuraman and Jiang, 2012-this issue). Imagine a situation in which an institution (e.g., a court of law) seeks to use neuroimaging to establish the veracity of an individual's memory. They have a template based on hundreds of individuals for what that individual's pattern of brain activity should look like for a true memory. Yet, the individual in question has a very different pattern of brain activity. Are they to conclude that the individual must not be experiencing a true memory? The veracity of memory is only one dimension that may explain why this individual's pattern of brain activity is so different from the other individuals. For example, there may have been fundamental differences in the individual's cognitive style that significantly affected their pattern of activity as well. If neuroimaging will be used to make an inference about an individual, then multiple dimensions in which individuals may differ must be considered.

We have shown previously that the topographical pattern of brain activity underlying a memory retrieval task can vary greatly from individual to individual, sometimes with little to no overlap in significant activations between individuals (Miller et al., 2002; Miller et al., 2009). However, despite that extensive variability, the individual patterns of brain activity are relatively consistent over time (Miller et al., 2002; Miller et al., 2009; for review of fMRI reliability, see Bennett and Miller, 2010), suggesting that differences in the patterns of brain activity are due to systematic differences in individual characteristics and are not due to random measurement error (see Fig. 1). In order to effectively use fMRI to infer unique aspects of the individual mind, it is necessary to untangle the critical factors that can vary the individual patterns of brain activity. In this study, we examine whether individual differences in strategy and cognitive style can account for the degree of similarity between any two individual patterns of brain activity during a retrieval task.

Using neuroscience methods to gain insight into the individual mind is a common goal among many institutions, including education (Byrnes, 2001; Posner and Rothbart, 2005), the military (National Research Council, 2008), and courts of law (Brown and Murphy, 2010). Implicit in the goals of these institutions is the ability to make judgments about an individual based on neuroscientific data collected from a group of individuals. This goal is often incompatible with the general scientific goal to make an inference about a general phenomenon that applies to a population by averaging data across individuals (Faigman, 2010). For fMRI in particular, this demand to average data across individuals is compounded by the fact that the signal-to-noise ratio (SNR) of the BOLD signal is very low (Friston et al., 1999) and that false positives due to the low SNR are far too common (Bennett et al., 2010). Yet, as acquisition devices and analytical tools for fMRI become more and more sophisticated, increasing effort is being made to infer unique aspects of the individual based on the group data.

A critical question remains within functional neuroimaging: do the results of a group analysis accurately represent the individuals that make up that group? Many studies have concluded that it does not (Heun et al., 2000; Machielsen et al., 2000; McGonigle et al., 2000; Miller et al., 2002; Feredoes and Postle, 2007; Seghier et al., 2008; Miller et al., 2009; Seghier and Price, 2009; Parasuraman and Jiang, 2012-this issue). For example, we found that the observed variations in functional brain activity across the whole brain during a simple recognition task were extensive, with some individuals activating mostly prefrontal regions while others activated mostly parietal regions (Miller et al., 2002; Miller et al., 2009). This was in contrast to the group analysis, which prominently showed both regions to be equally active. Are there quantifiable factors that might help to explain this effect? We found indirect evidence in a recent study that some variations in the degree of brain activity similarity between individuals during a memory retrieval task may be due to individual

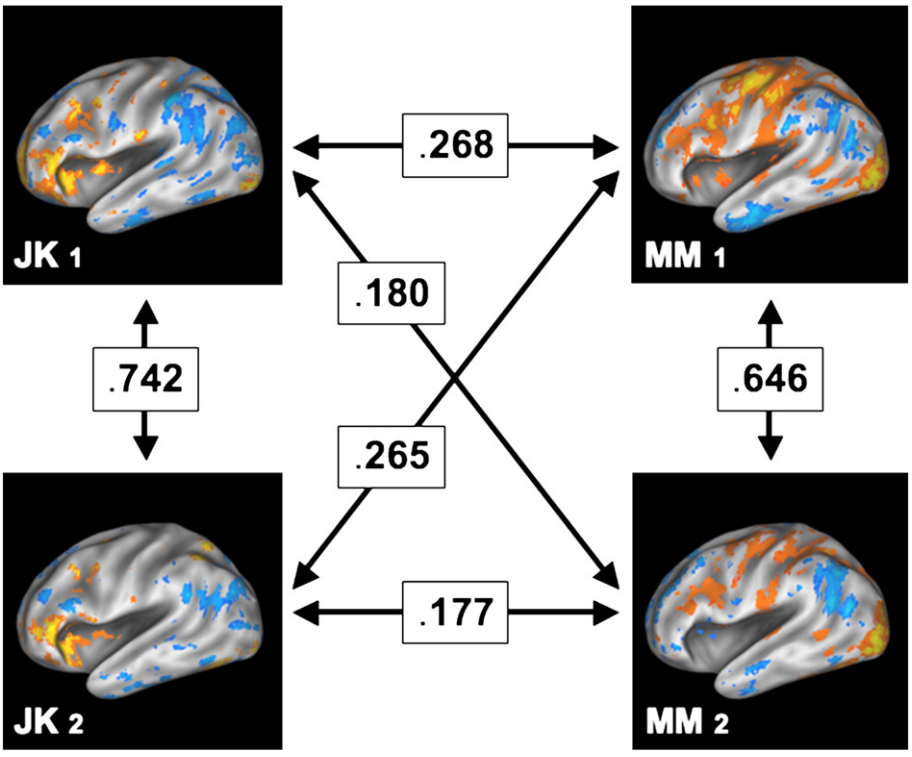

Fig. 1. Two participants from two scanning sessions held months apart representing the cross-correlation of unthresholded *t*-maps (retrieval>baseline) across subjects (average inter-individual correlation across all subjects = .224) and sessions (average intra-individual correlation across all subjects = .482). Each *r*-value represents the degree of similarity between individual *t*-statistic map volumes, i.e., the higher the *r*, the more similar the pattern of brain activity. The depiction of *t*-statistic maps is thresholded ($p<.001$ uncorrected) for visualization purposes only (adapted from Miller et al., 2009).