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Working memory for social information: Chunking or domain-specific buffer?

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ABSTRACT

Humans possess unique social abilities that set us apart from other species. These abilities may be partially supported by a large capacity for maintaining and manipulating social information. Efficient social working memory might arise from two different sources: chunking of social information or a domain-specific buffer. We test these hypotheses with functional magnetic resonance imaging (fMRI) by manipulating sociality and working memory load in an n-back paradigm. We observe (i) an effect of load in the frontoparietal control network, (ii) an effect of sociality in regions associated with social cognition and face processing, and (iii) an interaction within the frontoparietal network such that social load has a smaller effect than nonsocial load. These results support the hypothesis that working memory is more efficient for social information than for nonsocial information, and suggest that chunking, rather than a domain-specific buffer, is the mechanism of this greater efficiency.

Introduction

Humans make use of a formidable array of cognitive mechanisms to understand the beliefs, desires, intentions, and dispositions of their peers. This understanding makes society and culture possible and helps set us apart from other primate species (Herrmann et al., 2007). Social interactions require us to seamlessly process large quantities of incoming information, combine this input with our preexisting knowledge and beliefs, and produce goal-directed output. In order for any of this to occur in a sensible fashion, we must bear in mind some idea of what other individuals are like and what they are thinking and feeling. In other words, we must form, maintain, and continuously update impressions of others' dispositions and mental states.

The computational demands of social behavior suggest that another highly developed human faculty – working memory – may play a vital role in social cognition. Working memory consists of multiple cognitive mechanisms that allow for the active maintenance and manipulation of information. It allows us to perform mundane tasks such as holding onto a mental image or telephone number, as well as helping us to engage in complex behavior such as reading a book or playing chess (Baddeley and Hitch, 1974; Robbins et al., 1996). Evidence also demonstrates that working memory capacity is strongly correlated with general fluid intelligence (Kane et al., 2005). The cognitive neuroscience of working memory has already been well explored: considerable research points to the critical involvement of a network of frontoparietal regions including lateral prefrontal cortex, anterior cingulate cortex (ACC) and lateral posterior parietal cortex (PPC) (Braver et al., 1997; Chein et al., 2011; Owen et al., 2005; Smith, 2000). Additionally, a number of prefrontal regions have been tied to specific components of working memory specified in the classic theory of Baddeley and Hitch (1974). Dorsolateral prefrontal cortex (DLPFC) has been linked to manipulation of information consistent with central executive function, while more ventral portions of cortex manifest function consistent with domain-specific buffers: the phonological loop and visuospatial sketchpad (D'Esposito et al., 1998). It is worth noting, however, that the notion of domain-specific buffers is not necessary, i.e., mental representations may simply correspond to largely distributed patterns of neural activation (see Postle, 2006).

Despite its central role in higher order cognition, relatively little work has examined the role that working memory per se might play in social cognition and behavior. Although numerous social psychological theories discuss some form of “effortful processing,” they rarely go so far as to claim that this means working memory in particular. Indeed, some might argue against the involvement of working memory in social cognition on the basis of phenomenology: social interactions simply seem too easy to require a faculty that we typically associate with difficult tasks. For example, some forms of casual conversation involve shared knowledge, or common ground, which relieves cognitive burden (Nadig and Sedivy, 2002). Another puzzle emerges from the neuroimaging literature, in that the frontoparietal activity seems to generally be anticorrelated with activity in the default network — a set of regions with high resting metabolic activity and a tendency to deactivate relative to baseline during cognitively demanding tasks (Buckner et al., 2008; Raichle et al., 2001). The default network overlaps to a great extent with regions robustly engaged by social cognition such as medial prefrontal cortex (MPFC),

Abbreviations: FMRI, functional magnetic resonance imaging; ACC, anterior cingulate cortex; PPC, posterior parietal cortex; DLPFC, dorsolateral prefrontal cortex; MPFC, medial prefrontal cortex; TPJ, temporoparietal junction; IFG, inferior frontal gyrus; SMA, supplementary motor area; FG, fusiform gyrus; OFC, orbitofrontal cortex.

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the temporoparietal junction (TPJ) and medial PPC (Buckner and Carroll, 2007; Spreng et al., 2009). Thus working memory and social cognition might appear as antagonistic processes at first glance.

Social working memory

A number of studies have attempted to resolve this apparent conflict by shifting working memory into the social domain. Research by Druzgal and D'Esposito (2001, 2003) on working memory for facial identity marks an early foray into this territory. They initially found that working memory load increased activity in fusiform regions long associated with face processing (Kanwisher and Yovel, 2006; Kanwisher et al., 1997) and lateral prefrontal cortex (Druzgal and D'Esposito, 2001). However, upon closer examination they discovered that prefrontal activity tended to be more sustained (characteristic of working memory regions) over a delay period, while fusiform activity was more transient (characteristic of regions accessed during working memory) (Druzgal and D'Esposito, 2003). In another study, LoPresti and colleagues contrasted working memory for facial identity with working memory for emotional expressions (LoPresti et al., 2008). They replicated Druzgal and D'Esposito's earlier finding of transient activity in posterior face processing regions, but also demonstrated sustained activity in more anterior affective processing regions including orbitofrontal cortex (OFC), the amygdala and the hippocampus when participants held emotional face information in mind.

Most recently, Meyer et al. (2012) manipulated working memory load in a task that required reordering friends' names according to social dimensions such as friendliness. They replicated the classic working memory finding of load sensitivity in the frontoparietal network, but critically also observed that activity in social network regions – MPFC, TPJ and precuneus/posterior cingulate cortex – varied parametrically with load. This tantalizing result reverses the typical relationship between these networks and demonstrates that they can indeed function together when circumstances require it.

However, much more remains to be understood about the role of social network regions in working memory. One substantial gap in our knowledge stems from the fact that none of the previous studies have attempted to directly manipulate the sociality of information at the same time as working memory load. Meyer et al., the group that makes the strongest argument for social specificity, argue that the existing neuroimaging literature on working memory serves as an implicit control for their experiment. While this might be justifiable with regards to their primary finding – the effect of load within social regions – this approach leaves them unable to answer specific questions regarding the interaction between sociality and load. Most importantly, Meyer et al.'s study could not answer a fundamental question about social working memory: whether it taxes the classical working memory regions of the frontoparietal control network less so than a nonsocial control.

Efficiency hypotheses

The current study aims to fill this gap in the literature by directly manipulating both sociality and load within a single fMRI experiment. By doing so, we aim to determine two things: whether working memory for social information burdens the frontoparietal network less than working memory for comparable nonsocial information, and if so, whether this facilitation results from efficient chunking of social information or a domain-specific buffer.

The two theories being tested merit further explanation. The chunking hypothesis is based upon the well-known process of chunking, in which perceptual systems group associated low-level information into high level chunks (Gobet et al., 2001). It is important to note that chunking may occur as a deliberate retrieval strategy or as an automatic process, with the transition to automaticity mediated by practice. Given the high degree of familiarity people have with faces, we use chunking to refer to the automatic process throughout the paper. Druzgal and D'Esposito (2003) actually suggested the use of chunking in working memory for facial identity, and from there the extension to other social dimensions of faces and social information more generally is a relatively short one. By preprocessing – i.e. chunking – we may be able to reduce the complex sensory correlates of social data down to much more manageable representations of social information. Given the large number of facial features related to perceptions of trustworthiness (Oosterhof and Todorov, 2008), the reduction of this lengthy visual feature vector to a more manageable social representation may well explain increased efficiency in social working memory.

The buffer hypothesis also originates from classic working memory literature, in particular Baddeley's notion of domain-specific slave systems tied to the central executive. Baddeley and Hitch (1974) originally specified two such systems or buffers, the visuospatial sketchpad and the phonological loop. Later, Baddeley added a third slave system – the episodic buffer (Baddeley, 1992). The buffer hypothesis that we test proposes that people possess a buffer devoted to social information. The existence of such a buffer would allow more social information to be held in mind before overburdening the central executive. The possibility of a social buffer likely never surfaced before because until recently, social information was not considered a truly distinct domain of knowledge. However, the advent of social neuroscience has undermined the idea that social cognition can be explained entirely in terms of domain general cognition mechanisms and generated support for the idea of a sovereign social domain in the brain (Mitchell, 2009). We presume that the non-social control condition in our experiment – which involves spatial locations – makes use of the visuospatial sketchpad.

These two theories make distinct predictions about the behavioral and neural effects of manipulating sociality of information and working memory load. Chunking requires a combination of perceptual resources and executive attention (Bor et al., 2003). Thus, the chunking hypothesis predicts an up-front cost of preprocessing chunks, one that would manifest as a negative main effect of sociality on behavioral performance (that is, slower reaction times to social vs. non-social information) and a positive main effect of sociality on activity in regions associated with social perception. In previous research, regions associated with domain-specific buffers have shown parametric increases in activity in response to load when the relevant type of information was presented (D'Esposito et al., 1998). Thus, the buffer hypothesis predicts an interaction between sociality and load in regions associated with social cognition such that neural activity should scale with load only in the social condition. The result of the research of Meyer et al. (2012) already lends support to this hypothesis, although without the control condition necessary for a direct test of the predicted interaction. The key difference between chunking and buffer hypotheses resides, therefore, within regions activated by the main effect of sociality: the buffer hypothesis predicts a flexible domain-specific resource that scales with load while the chunking hypothesis predicts load-invariant perceptual preprocessing. Of course, consistent with the considerable extant literature, both hypotheses would predict an increase in frontoparietal activity and a decrement in performance with increased load. Finally, the overall hypothesis of efficient social working memory predicts an interaction between sociality and load such that the simple effect of load is smaller within the social condition than within the nonsocial condition in terms of both behavioral performance and neural activity in the frontoparietal network.

Material and methods

Participants

Sixteen participants (10 female, mean age = 22, $SD = 2.3$) were recruited from the Princeton University community. All participants were right-handed, neurologically normal, had normal or corrected-to-normal vision and were fluent in English. Participants provided informed