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**The common neural basis of autobiographical memory, prospection,
navigation, theory of mind and the default mode: a quantitative meta-
analysis**

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11 The common neural basis of autobiographical memory, prospection, navigation, theory of
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13 mind and the default mode: a quantitative meta-analysis
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52 Abbreviations: ALE = Activation likelihood estimation, BA = Brodmann area.
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Abstract

A core brain network has been proposed to underlie a number of different processes, including remembering, prospection, navigation and theory-of-mind (Buckner RL, Carroll DC. 2007. *Trends in Cognitive Sciences*, 11: 49–57). This purported network—medial prefrontal, medial temporal, and medial and lateral parietal regions—is similar to that observed during default-mode processing and has been argued to represent self-projection (Buckner & Carroll, 2007) or scene-construction (Hassabis D. Maguire EA. 2007. *Trends in Cognitive Sciences*, 11: 299-306). To date, no systematic and quantitative demonstration of evidence for this common network has been presented. Using the activation likelihood estimation (ALE) approach, we conducted four separate quantitative meta-analyses of neuroimaging studies on: (a) autobiographical memory, (b) navigation, (c) theory-of-mind, and (d) default mode. A conjunction analysis between these domains demonstrated a high degree of correspondence. We compared these findings to a separate ALE analysis of prospection studies and found additional correspondence. Across all domains, and consistent with the proposed network, correspondence was found within the medial temporal lobe, precuneus, posterior cingulate, retrosplenial cortex and the temporoparietal junction. Additionally, this study revealed that the core network extends to lateral prefrontal and occipital cortices. Autobiographical memory, prospection, theory-of-mind and default mode demonstrated further reliable involvement of the medial prefrontal cortex and lateral temporal cortices. Autobiographical memory and theory-of-mind, previously studied as distinct, exhibited the most extensive functional overlap. These findings represent quantitative evidence for a core network underlying a variety of cognitive domains.

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A single core network has recently been proposed to underlie a number of cognitive domains previously seen as distinct, specifically: (a) remembering, (b) prospection, (c) spatial navigation, and (d) theory-of-mind (Buckner & Carroll, 2007). The network of brain regions hypothesized to be common to these domains comprise the frontopolar and anterior midline structures in addition to the medial temporal lobe, medial parietal and a lateral posterior parietal region, the temporoparietal junction. These authors believe that the core network may support self-projection: the ability to mentally project oneself from the present moment into a simulation of another time, place or perspective. Additionally, the default mode network (Mazoyer et al., 2001; Raichle et al., 2001; Schulman et al., 1997)—the set of brain areas typically found to be associated with stimulus-independent thought (McGuire, Paulesu, Frackowiak, & Frith, 1996; Mason et al., 2007)—may be similar in composition, perhaps indicating that this activation pattern signals a shift from the processing of external stimuli to internal and imagined situations (Buckner & Carroll, 2007).

This intriguing proposal has generated a great deal of interest, evidenced in part by a prompt response arguing that scene-construction, and not self-projection, provides a more specific and empirically supported account of the core network (Hassabis & Maguire, 2007). Constructing a complex and coherent scene involves the retrieval and integration of information towards the visualization of a spatial context that can be maintained and manipulated. The position of Hassabis & Maguire (2007) is supported by the observation that the pattern identified by Buckner and Carroll (2007) is also observed when individuals imagine fictitious circumstances that may have no relation to the self or time (Hassabis & Maguire, 2007; Hassabis, Kumaran & Maguire, 2007).

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Missing from both proposals is concrete evidence that a reliable pattern of brain activity is observed across these domains. Both groups (Buckner & Carroll, 2007; Hassabis & Maguire, 2007) rely upon a narrative-based review to present evidence, citing studies suggestive of a similar network rather than employing a systematic and quantitative approach. Before any debate regarding the explanatory depth of self-projection or scene-construction can take place, it is necessary to demonstrate that a core network truly is common to all these domains. Applying a systematic, extensive and quantitative meta-analytic approach that can properly evaluate the evidence for this hypothesized neural system is a necessary undertaking. The domains thought to reflect this common system are described in brief below along with their possible relation to self-projection or scene-construction.

Remembering

Remembering the past appears to be related to both self-projection and scene-construction, especially upon consideration of the theory of auto-noetic awareness (Tulving, 1985; Wheeler, Stuss, & Tulving, 1997). According to this theory, declarative memory is based on two systems that correspond to distinct subjective states of awareness: noetic and auto-noetic. Noetic awareness involves the recall of knowledge or facts, and supports semantic memory. Auto-noetic awareness supports the remembering of contextual and subjective associations from the original experience or episodic memory. Episodic recollection of personal events from one's own life is referred to as autobiographical memory. During autobiographical recall, spatially- and temporally-bound information is retrieved and the relevant scene vividly reconstructed. This is accompanied by a feeling of reminiscence, where the self being remembered is the same

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3 self engaged in recollection, and the re-experiencing of these memories may elicit strong
4 emotions. Remembering thus involves a process of projecting the self back through time,
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6 as well as constructing a past scene and experience. Auto-noetic awareness, however, may
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8 also be applied in a more flexible fashion, to other domains such as imagining the future.
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11 12 *Prospection*

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15 Imagining ourselves in the future, or prospection, plays an integral role in
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17 planning, allowing one to plot strategic behavior in order to engage in successful goal
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19 pursuit (Levine, Freedman, Dawson, Black, & Stuss, 1999). Through the mental
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21 simulation of possible futures and their outcomes we can avoid negative ends and
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23 maximize positive ones. A number of theorists have hypothesized that remembering and
24
25 future-oriented thinking may reflect a single underlying process (Suddendorf & Corballis,
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27 1997; Wheeler et al., 1997; Atance & O'Neill, 2001). This idea has only recently been
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29 supported by empirical data. In one study, for example, the temporal distribution of self-
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31 generated, probable future events (the “intention function”) maps almost identically onto
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33 the distribution of recalled past events (the “retention function”); this close similarity
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35 replicates across individuals at different points in their lifespan (Spreng & Levine, 2006).
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37 Other researchers have shown that the descriptions of both past and future events show
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39 decreasing phenomenological richness with increasing time from the present
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41 (D’Argembeau & Van der Linden, 2004), and that the episodic specificity of past and
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43 future events decline with age in an equivalent fashion (Addis, Wong, Schacter, 2008). It
44
45 is thus likely that a shared mechanism for remembering and prospection exist, and
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47 reflects a shared neural substrate.
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Navigation

Topographical orientation involves the capacity to navigate spatial environments (Maguire, 1997), largely by imagining one's current position, the desired endpoint, and possible routes using both egocentric and allocentric perspectives. The latter perspective involves considering the relation between landmarks irrespective of an individual's viewpoint (Aguirre, Zarahn, & D'Esposito, 1998). This may involve either projecting the "mind's eye" into a perspective separate from the immediate environment, or the construction of a scene or map of our environs.

Theory-of-Mind

A key aspect of successful social navigation involves our possession of a theory of mind, that is, an understanding that the behavior of others is motivated by internal states such as thoughts, emotions, and beliefs (a.k.a. mentalizing; Carruthers & Smith, 1996). Understanding others, in part, involves the taking of another's perspective in order to predict their actions and reactions (Garfield, Peterson, & Perry, 2001). Simulation-based accounts of theory-of-mind are broadly consistent with the idea that self-projection is an important aspect of mentalizing, proposing that we take on the mindset of others and use our self to simulate their experience in order to understand them (Blakemore & Decety, 2001; Carruthers & Smith, 1996; cf. Stich & Nichols, 1992 for a propositional account). In constructing simulations of actors' potential actions and reactions, we may employ self-projection or perhaps construct imaginary scenes of potential situations.

Default Mode

The pattern of brain activation observed in participants during rest conditions (Schulman et al., 1997; Mazoyer et al., 2001) has been called the default mode of brain

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3 function (Raichle et al., 2001) and may represent stimulus-independent thought or mind-
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5 wandering (Mason et al., 2007). Driven not by attention to the external environment, but
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7 an internal mode of cognition, the default mode may set the stage for self-projection or
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9 scene-construction by enabling a switch in perspective from the external to the internal
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11 (Gusnard, Akbudak, Shulman, & Raichle, 2001, see also Raichle & Gusnard, 2005).
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15 *The Current Study*

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17 The aim of the present study is to assess the correspondence of neural activations
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19 across multiple studies for autobiographical memory, prospection, navigation, theory-of-
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21 mind and default mode using the activation likelihood estimation (ALE) approach to
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23 quantitative meta-analysis for neuroimaging data (Laird, Fox et al., 2005; Turkeltaub,
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25 Eden, Jones, & Zeffiro, 2002). We employed the ALE approach to reveal statistically
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27 significant concordance of activated voxels across numerous experiments for each
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29 domain while controlling for chance clustering. By seeking concordance at the voxel
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31 level, ALE tests for statistically reliable clustering of activations in standardized
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33 locations, avoiding spatial distinction errors and problematic incongruence of labeling
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35 across studies that can befall tabular meta-analytic approaches and narrative-based
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37 reviews. A subsequent conjunction analysis can then assess correspondence across
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39 domains by identifying where clusters from different domains either directly overlap or
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41 converge within brain structures.
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48 To date, six neuroimaging studies have explicitly examined prospection (Addis,
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50 Wong, & Schacter, 2007; D'Argembeau, Xue, Lu, Van der Linden & Bechara, in press;
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52 Okuda et al., 2003; Sharot, Riccardi, Raio & Phelps, 2007; Botzung, Denkova &
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54 Manning, 2008; Szpunar, Watson, & McDermott, 2007). Because of this small number of
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3 studies, prospection was not assessed in the conjunction analysis. However, brain regions
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5 reliably activated by prospection were compared with the other domains.
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8 Methods

9 10 *Selection of Studies*

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12 Studies for autobiographical memory, navigation, theory-of-mind and default
13 mode were selected using a systematic search process. Peer-reviewed articles published
14 in English between January 1985 and June 2007 were selected from the search results of
15 three separate databases: (1) PsycInfo, (2) Medline, and (3) Science Citation Index.
16
17 Keyword searches were conducted using the following terms: (1) “neuroimaging” <OR>
18 “fMRI” <OR> “PET,” and the domain-specific terms (2i) “autobiographical memory,”
19 (2ii) “navigation,” (2iii) “theory-of-mind” <OR> “mentalizing” <OR> “mindreading,”
20 and (2iv) “default mode” <OR> “default network” <OR> “default state” <OR>
21 “stimulus-independent thought.” As a result, 117 unique papers were found on
22 autobiographical memory, 142 for navigation, 135 for theory-of-mind, and 118 for
23 default mode. Theoretical papers and reviews were excluded, as were studies that did not
24 provide data on non-clinical samples (e.g., Castelli, Frith, Happé, & Frith, 2002), studies
25 that did not report activation foci as 3-D coordinates in stereotaxic space (e.g., Berthoz et
26 al., 1997), or those that used ‘rest’ or ‘fixation’ as a control condition (which effectively
27 controlled for default mode, preventing an examination of overlap with stimulus-
28 independent thought; e.g., Platek, Keenan, Gallup Jr., & Mohamed, 2004; Cabeza et al.,
29 2004). For studies containing multiple independent samples, all appropriate data were
30 included (e.g., Walter et al., 2004). The reference lists of these papers were searched for
31 additional studies that fit these criteria. Domain-specific exclusions are described below.
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Autobiographical memory papers that did not directly examine the retrieval of an autobiographical memory were excluded (e.g., episodic or semantic memory tasks; Sugiura et al., 2007), or those that employed another type of autobiographical memory as a contrast condition (e.g., recent versus remote; Maguire & Frith, 2003; or sad versus happy, Markowitsch et al., 2003; see Svoboda, McKinnon & Levine, 2006 for a meta-analysis examining autobiographical memory). In total, 19 appropriate studies were included (Table 1).

A total of 13 studies were included for the navigation domain once studies that did not involve the retrieval of allocentric or egocentric spatial information were excluded (Table 2). Studies that examined encoding were not included in the present study because the process of encoding necessarily involves attention to the present environment (e.g., spatial exploration; Maguire, Frackowiak & Frith 1996). Studies tapping the retrieval of spatial location (e.g., Parslow et al., 2004; Harrison, Duggins & Friston, 2006) were judged not to reflect navigation from one point to another (i.e., wayfinding) and were therefore excluded.

In the case of theory-of-mind, studies were excluded if they did not involve a basic theory-of-mind task but reported a more narrow investigation (e.g., examination of the role of self-other similarity; Mitchell, Macrae, & Banaji, 2006), or if the task did not clearly involve inferring the mental state of another (e.g., hearing one's own name; Kampe, Frith, & Frith, 2003). Additionally, papers with emotional stimuli (e.g., emotional faces or disturbing pictures; Dolan & Frith, 2004) were excluded in the interests of drawing a more homogeneous sample. In the end, a total of 50 studies met the criteria for inclusion in the theory-of-mind meta-analysis. Due to the relatively large

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3 number of foci (compared to other domains) and potential inflation of cluster size as a
4 result (Laird, Fox et al., 2005), a randomly determined (via random number generation)
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8 subsample of studies was selected that approximately matched the number of foci for this
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10 domain with the number of foci in the next most extensive domain (i.e., autobiographical
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12 memory). A total of 30 theory-of-mind studies were included (Table 3).
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16 Studies on default mode included those reporting foci for either task-related
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18 deactivations (e.g., Schulman et al., 1997) or activations (e.g., Mason et al., 2007)
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20 associated with rest or fixation. Studies were excluded if they examined brain
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22 deactivations associated with cognitively-demanding tasks relative to another active task
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24 (e.g., covert counting vs lexical retrieval; Hutchinson et al., 1999), if the baseline or rest
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26 condition involved responding to an external stimulus (e.g., flashing screen; Gilbert,
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28 Simons, Frith, & Burgess 2006), or if the study constituted a functional connectivity
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30 analysis rather than a typical contrast analysis (e.g., Greicius, Krasnow, Reiss & Menon,
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32 2003). In total, 16 studies of the default network were included in the analysis (Table 4).
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37 A surge in neuroimaging studies examining prospection has begun to unravel the
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39 neural underpinnings of future-oriented thinking. In light of these papers, we have elected
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41 to loosen the inclusion criteria and incorporate six papers into a separate ALE analysis
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43 (Table 5). Unlike the afore-mentioned domains, we included studies with baseline
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45 conditions equivalent to our other task domains (e.g., theory-of-mind control task,
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47 Szpunar et al., 2007; fixation, Sharot et al., 2007) and contacted the authors for
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49 information on unpublished contrasts of interest (Future > Control; Addis et al., 2007;
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51 Sharot et al., 2007; Szpunar et al., 2007). Due to the small number of studies, collection
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55 of papers outside the designated time window, and reliance upon unpublished results, we
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3 do not include prospection in the conjunction analysis with the other four domains.
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6 Patterns of brain activity identified by the prospection meta-analysis are, however,
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8 discussed in light of those identified by the conjunction analysis.
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11 *[Insert Tables 1 to 4 about here]*
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13 *Creation of ALE Maps for Each Domain*

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15 The ALE method provides a voxel-based meta-analytic technique for functional
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17 neuroimaging data (Turkeltaub et al., 2002). The software (BrainMap Search&View
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19 3.2.1) computes statistically significant concordance in the pattern of brain activity
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21 among several independent experiments. ALE maps are derived based on foci of interest,
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23 which comprise statistically significant peak activation locations from multiple studies.
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27 The original studies contributing these foci for each domain are presented in
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29 Tables 1-5. Coordinates reported in MNI were converted to Talairach using the Brett
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31 transformation (Brett, 1999). In the approach taken by ALE, localization probability
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33 distributions for the foci are modeled at the center of 3-D Gaussian functions, where the
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35 Gaussian distributions are summed across the experiments to generate a map of inter-
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37 study consistencies that estimate the likelihood of activation for each voxel, the ALE
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39 statistic, as determined by the entire set of studies. Voxel sizes were determined at full-
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41 width half-maximum of 10mm. The ALE values are computed using the same full-width
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43 half-maximum value and for each domain, randomly generated foci (identical in number
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45 to those being tested) were employed as the null set across 5000 permutations. The false
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47 discovery rate method was employed to correct for multiple comparisons at a significance
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49 threshold of $p < .05$ (Laird, Fox et al., 2005). For each of the five domains, ALE maps
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51 and cluster reports were generated. Anatomical labels were then applied to the resultant
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3 clusters using the Talairach Daemon and visual inspection (for greater detail on the ALE
4 method, see Laird, Fox et al., 2005; Turkeltaub et al., 2002; for a discussion of meta-
5 analytic approaches to neuroimaging data, see Wager, Lindquist & Kaplan, 2007).
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10 *Conjunction Analysis*

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12 The ALE maps were imported into AFNI (Cox, 1996) and a conjunction analysis
13 was undertaken to examine the correspondence of consistently activated regions across
14 autobiographical memory, navigation, theory-of-mind and default mode. Conjunction
15 was determined by creating a mask, using 3dcalc, and overlaying the resultant ALE maps
16 for each domain onto an anatomical template in Talairach space (Talairach & Tournoux,
17 1988) to visualize cluster overlay (N.B. this does not constitute a statistical test). The
18 location of overlapping clusters is reported in Talairach coordinates.
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29 Results

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31 Domain-specific ALE results are presented in Figure 1 and Tables 6-10.
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33 Discussion of the individual meta-analyses performed for each domain is unfortunately
34 outside the scope of this paper (see Cabeza & St. Jacques, 2007; Spiers & Maguire, 2007;
35 Gallagher & Frith, 2003; Buckner, Andrews-Hanna & Schacter, in press; Schacter, Addis
36 & Buckner, in press, for reviews on these topics). The results of the conjunction reveal
37 correspondence of ALE clusters across four or three cognitive domains in a number of
38 locations and is described below (also Table 11 and Figure 2) along with their
39 consistency with propection findings (Table 11). Correspondence across domains is said
40 to occur if, (a) ALE clusters directly overlapped within 3-D space or, (b) if clusters
41 converge within the same brain structure. Clusters are said to converge if they fall within
42 10mm of each other, and are within the same Brodmann Area (BA) or unlabeled region
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3 (e.g. hippocampus). Prospection is reported to be consistent with the conjunction analysis
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5 if the ALE output demonstrates a similar cluster in the same brain region. This method of
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7 determining convergence across domains with prospection is similar to the determination
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9 of co-activation using a tabular method.
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13 The conjunction analysis was also utilized to determine differences in cluster
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15 location among the domains. Domain-specific clusters that are unshared and unique to a
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17 particular domain are noted in Tables 6-9. Unique clusters are defined as occurring at a
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19 distance greater than 10mm from any other cluster. Additionally, a cluster that converges
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21 with another in one BA may extend to an additional region in isolation. These are noted
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23 in Tables 6-9 as well.
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27 *[Insert tables 5-8 about here]*
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29 All four domains demonstrated correspondence within the medial temporal lobe,
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31 medial parietal regions, the temporoparietal junction, the occipital lobe and lateral
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33 prefrontal cortex. When considering all domains except for navigation, two additional
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35 areas showed correspondence: the medial prefrontal and lateral temporal regions.
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37 Prospection was associated with all of these areas except for the occipital lobe. The
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39 extent of convergence and overlap within each region is reviewed below.
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43 *Medial temporal lobe*

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45 All four domains converged within the left medial temporal lobe. Direct overlap
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47 was observed within the left parahippocampal gyrus (BA 36) [-28, -35, -10] and all
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49 domains except default mode converged within the left hippocampus. Differences in the
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51 pattern of medial temporal clusters were also observed. Autobiographical memory
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53 demonstrated far more expansive left medial temporal clusters compared with the other
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3 domains (Table 5). Navigation engaged the medial temporal lobes bilaterally and
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5 extended more posteriorly compared with autobiographical memory (Table 6).
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Prospection also engaged the parahippocampus and hippocampus bilaterally.

Medial Parietal Regions

Convergence in the precuneus, posterior cingulate and retrosplenial cortex was extensive for all four domains. Within the precuneus and posterior cingulate, direct overlap was observed in the right hemisphere [6, -59, 17] and left hemisphere [-5, -50, 30] for all domains except navigation. On the left, an additional point of convergence was observed with all domains except theory-of-mind [-10, -57, 24]. Retrosplenial cortex clusters were observed bilaterally for autobiographical memory and navigation, on the right for theory-of-mind and on the left for default mode. All three medial parietal areas were reliably involved in prospection, bilaterally.

Temporoparietal Junction & Occipital Lobe

All domains engaged the temporoparietal junction. Within the right hemisphere, all domains converged in the temporoparietal junction. In the left hemisphere, direct overlap was observed for all domains except for navigation [-42, -68, 37], with navigation converging in close proximity. For theory-of-mind, temporoparietal clusters extended anteriorly into BA 40, whereas the other domain clusters extended posteriorly from the temporoparietal junction to occipital cortex (BA 19) where they overlapped in the left hemisphere [-38, -80, 31]. Prospection also involved the left temporoparietal junction but not the occipital lobe.

Lateral Prefrontal Cortex

All four domains reliably involved the left lateral prefrontal cortex. Convergence occurred in left ventrolateral prefrontal cortex (inferior frontal gyrus; BA 47) between all domains save default mode. Prospection also engaged the left ventrolateral prefrontal cortex.

Medial Prefrontal Cortex

Autobiographical memory, theory-of-mind and default mode, but not navigation, demonstrated additional correspondence in the medial prefrontal cortex. Convergence extended throughout the medial prefrontal cortex and rostral anterior cingulate (BA 32) with direct overlap observed within the frontal pole (BA 10) [0, 51, 2]. Prospection clusters were also observed throughout the frontal pole and frontal midline structures.

Lateral Temporal Lobe

Convergence was observed for autobiographical memory, theory-of-mind and default mode throughout the left and right lateral temporal lobe (BAs 21, 22). Prospection also engaged these regions within the left hemisphere.

*****Insert Figures 1 & 2 about here*****

Discussion

The strength of evidence for the presence of a core network that underlies multiple cognitive domains was assessed through quantitative ALE meta-analyses. By examining conjunction across autobiographical memory, navigation, theory-of-mind and default mode, correspondence was found in the predicted regions (Buckner & Carroll, 2007) and areas not originally proposed. A high degree of agreement was also observed between the output of this conjunction and prospection. The results provide evidence in

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3 favor of a core set of brain regions within the default network that underlie remembering,
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6 prospection, navigation, and theory-of-mind. These results also lend support to both the
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9 self-projection and scene-construction account of a core network by providing extensive,
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12 quantitative evidence of a common set of functional neural correlates. The pattern of
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15 activation across domains demonstrates that far more is shared than unique. Shared
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18 clusters had higher ALE values and far outweighed the number of unique clusters, which
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21 tended towards lower ALE values. Less than a quarter of clusters were domain-specific.
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24 Autobiographical memory, prospection, navigation and theory-of-mind engage the
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27 default network in the medial temporal lobes, medial parietal regions and the
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30 temporoparietal junction, as predicted by Buckner and Carroll (2007). However, these
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33 domains also engage the lateral prefrontal cortex and the occipital cortex, regions not
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36 initially predicted to be part of the core network. This finding illustrates the advantages of
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39 the ALE approach over narrative reviews. The lateral prefrontal cortex potentially serves
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42 to maintain and manipulate information held online (D'Esposito, Postle, Ballard, &
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45 Lease, 1999), possibly sustaining a mental simulation or scene. Occipital cortex
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48 involvement likely supports mental imagery processes (Farah, 1989), useful for visual
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51 simulation or imagining scenes.
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[Insert Table 11 about here]

Autobiographical memory, prospection and theory-of-mind demonstrate further functional correspondence, activating the remaining areas of the default network: medial prefrontal cortex and lateral temporal regions (e.g., Schulman et al., 1997; Buckner, Andrews-Hanna & Schacter, in press). Although not predicted by Buckner and Carroll (2007), lateral temporal regions have been previously noted to be involved in

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3 autobiographical memory (Svoboda et al., 2006), theory-of-mind (Gallager & Frith,
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6 2003), default mode (i.e., task-related deactivations; Schulman et al., 1997) and has been
7
8 implicated in prospection as well (Schacter, Addis, & Buckner, 2007).
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11 Why is less correspondence observed for navigation? While navigation primarily
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13 involves the retrieval of a detailed visuospatial context, this context does not necessarily
14
15 involve the self or semantic information. Self-related processes engage the medial
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17 prefrontal cortex (Craig et al., 1999; D'Argembeau et al., 2007; Johnson et al., 2002;
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19 Mitchell, Banaji, & Macrae, 2005; Northoff & Bermpohl, 2004; Ochsner et al., 2005) and
20
21 appear likely to be involved in autobiographical memory, prospection, theory-of-mind
22
23 and default mode processing. Likewise, navigation appears less likely to involve the
24
25 recollection of semantic information than the other domains, a process tied to the lateral
26
27 temporal cortices (Martin & Choa, 2001). Medial prefrontal and lateral temporal
28
29 involvement may add to the richness of a scene, bringing a range of personal,
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31 interpersonal, temporal and semantic detail online.
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38 This core network may be involved in more processes than presently reviewed.
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40 One potential additional domain is engagement with narrative fiction. A review of story-
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42 processing studies found that the associated brain areas are similar to those involved in
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44 autobiographical memory and theory-of-mind (Mar, 2004). This correspondence was
45
46 interpreted as evidence that theory-of-mind reasoning and autobiographical recollection
47
48 are engaged during story processing. A number of theorists and researchers have argued
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50 for a close link between social cognition and narrative processing (e.g., Bruner, 1986;
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52 Keen, 2007; Mar & Oatley, in press; Mar, Oatley, Hirsh, dela Paz, & Peterson, 2006;
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54 Oatley, 1999; Palmer, 2004; Peskin & Astington, 2004; Zunshine, 2006). A core network
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3 involved in simulating different times, different spaces, and other minds (Buckner &
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5 Carroll, 2007) or constructing complex coherent scenes (Hassibis & Maguire, 2007)
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8 could thus also play a role in narrative processing as well.
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11 Beyond exploring the role of a core network that contributes to a broad number of
12
13 domains, a more narrow investigation of the parallel between theory-of-mind and
14
15 autobiographical memory could prove informative. These two domains displayed the
16
17 greatest degree of overlap in the conjunction analysis. Autobiographical memory and
18
19 theory-of-mind demonstrated similar patterns of activity from the ventrolateral and
20
21 medial prefrontal cortex, to the precuneus, posterior cingulate and retrosplenial cortex;
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23 into the medial temporal region and amygdalae; and from the temporoparietal junction,
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25 down the superior temporal sulcus and middle temporal gyrus to the temporal poles. Both
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27 autobiographical memory and theory-of-mind require meta-representational ability
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29 (Perner, 2000), where there must be an awareness of the relation between knowledge
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31 sources and present knowledge states; one must possess a theory-of-mind for oneself in
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33 order to acknowledge the past self in relation to the present rememberer. Moreover, there
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35 are evolutionary reasons to believe that autobiographical memory and theory-of-mind
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37 should be functionally bound.
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44 It has been argued that hominid brain evolution was driven by social selection
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46 pressures (Humphrey, 1976). These pressures gave rise to complex social processes such
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48 as deception, perspective taking, and alliance building (Byrne & Whiten, 1988; Dubar,
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50 1993). A likely component to the evolution of these attributes is the ability to remember
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52 specific social encounters and the changing social conditions among group members.
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55 Stimulus-bound actions and semantic memory would not be sufficient to adaptively
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3 inform cooperative/competitive decision-making and accommodate rapidly changing
4 social dynamics. This may explain why many autobiographical memories and plans are
5 characterized by social events (de Vries & Watt, 1996; Larocque & Oatley, 2006). The
6 contents of memory and prospection may be necessarily and adaptively tied to things
7 social in nature, potentially the most behaviorally-relevant stimuli. As such, the
8 evolutionary advancement of autothetic awareness would correspond to the neural
9 processes of theory-of-mind. The utilization of prospection is arguably of greatest
10 strategic importance, particularly in the securing of mates, protection, and resources
11 (Flinn, Geary, & Ward, 2005; Suddendorf & Corballis, 2007).
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24 Both theories of self-projection and scene construction emphasize the role of the
25 medial temporal lobes (Buckner & Carroll, 2007; Hassibis & Maguire, 2007). Medial
26 temporal lobe involvement in the core network may reflect a common reliance on
27 mnemonic or relational processes (Moscovitch, Nadel, Winocur, Gilboa, & Rosenbaum,
28 2006; Squire & Zola-Morgan, 1991; Eichenbaum, 2000). The function of the medial
29 temporal lobe may also apply more broadly towards the construction of coherent scenes,
30 events (Hassibis & Maguire, 2007) and mental models (Schacter & Addis, 2007). Rich
31 memories allow one to find commonalities between current events and the past. Pattern-
32 matching paired with the flexible reconstruction of information allows for the application
33 of recollection to social problem-solving. Not all theory-of-mind tasks, however,
34 necessarily require this mnemonic component. The hippocampus may not be necessary to
35 support theory-of-mind as it does autobiographical memory and other aspects of scene
36 construction (Hassibis & Maguire, 2007; Maguire, 1997; Moscovitch et al., 2006; e.g.,
37 Hassibis Kumaran, Vann, & Maguire, 2007; Rosenbaum et al., 2000) as evidenced in part
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3 by two patients with episodic memory impairment who have been shown to perform well
4 on theory-of-mind tasks (Rosenbaum, Stuss, Levine & Tulving, 2007). Further work will
5 be required to delineate the neural relationship between the interpersonal and the
6 autobiographical.
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12 While we believe that our approach has many strengths, particularly over tabular
13 meta-analyses and narrative reviews, our method does have some limitations. Lack of
14 direct overlap across all of the domains studied may be due to the relative paucity of
15 published neuroimaging investigations of relevant aspects of navigation (i.e., allocentric
16 recall) and prospection. The small number of available foci for inclusion in these ALE
17 analyses may reduce the probability of identifying reliable clusters. Additionally, because
18 foci are pooled across studies and treated as fixed effects, individual studies may exert
19 undue influence (Wager, Lindquist & Kaplan, 2007). Some limitations are tempered by
20 the quantification of cluster coherence provided by the ALE statistic (e.g., few theory-of-
21 mind studies report activity in the medial temporal region as compared to the medial
22 frontal cortex and the values of the ALE statistic reflects this. See Table 8). Despite its
23 limitations, the ALE technique has demonstrated convergent validity with other
24 approaches to meta-analysis (e.g., tabular methods in the case of autobiographical
25 memory Gilboa, 2004; Svoboda et al., 2006; see also Laird, McMillan et al., 2005) while
26 contributing more sophisticated statistical threshold calculations (Laird, Fox et al., 2005).
27 Additionally, the correspondence we observed between autobiographical memory and
28 default mode is consistent with previous observations (Buckner et al., 2005; Raichle, et
29 al, 2001; Andreasen et al., 1995) and validates our approach to determining
30 correspondence of functional neuroanatomy across domains. Causal inferences with
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3 respect to the relation between brain-region and brain function, however, cannot be made
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5 without convergent neuropsychological evidence. Evidence of co-occurring functional
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7 deficits across domains due to neurological insult within the core network is less well
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9 characterized (for exceptions, see Hassabis, Kumaran, Vann, & Maguire, 2007;
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11 Rosenbaum et al., 2000, 2007).
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15 One alternative explanation for our data is that functional similarities between
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17 tasks may reflect the coincident activation of multimodal regions, not a core network.
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19 Also, neural demands from different domains may recruit similar and overlapping brain
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21 areas, but not be functionally dependent upon the same neurons. One other concern is that
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23 our analysis relies on group data for each data-point, which means that small differences
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25 in anatomic localization between individuals are necessarily obscured. In light of this
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27 fact, it must be acknowledged that this is a somewhat broad approach and there are likely
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29 subtle distinctions that have not been captured. Despite a correspondence of data across
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31 more than 1000 participants, correspondence at the individual level remains unknown and
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33 certainly worth further investigation.
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39 In this study, we empirically demonstrated reliable patterns of brain activity
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41 common across a number of cognitive tasks. In addition to medial prefrontal, medial
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43 temporal, and parietal regions (Buckner & Carroll, 2007), our analysis has revealed
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45 evidence of an extended core network that includes lateral prefrontal cortex, lateral
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47 temporal cortex and the occipital lobe. The correspondence of functional neuroanatomy
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49 across domains suggests a core network may be involved in the execution of a broad set
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51 of domains. This core network may support a set of processes that promote self-
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53 projection (Buckner & Carroll, 2007), scene-construction (Hassabis & Maguire, 2007), or
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3 some other as yet unidentified cognitive account. While this meta-analytic study does not
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5 allow for a verdict to be delivered regarding these differing theories, it contributes toward
6
7 the overall endeavor of an exciting, integrative, cross-disciplinary approach to cognitive
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9 neuroscience.
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57
58
59
60

References

- Addis, D. R., Wong, A. T., & Schacter, D. L. (2007). Remembering the past and imagining the future: Common and distinct neural substrates during event construction and elaboration. *Neuropsychologia*, *45*, 1363-1377.
- Addis, D.R., Wong, A.T. & Schacter, D.L. (2008). Age-related changes in the episodic simulation of future events. *Psychological Science*, *19*, 33-41.
- Aguirre, G. K., Zarahn, E., & D'Esposito, M. (1998). Neural components of topographical representation. *Proceedings of the National Academy of Sciences of the United States of America*, *95*, 839-846.
- Allison, T., Puce, A., & McCarthy, G. (2000). Social perception from visual cues: Role of the STS region. *Trends in Cognitive Sciences*, *4*, 267-278.
- Atance C.M., & O'Neill D.K. (2001). Episodic future thinking. *Trends in Cognitive Sciences*, *5*, 533-539.
- Berthoz, A. (1997). Parietal and hippocampal contribution to topokinetic and topographic memory. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences*, *352*, 1437-1448.
- Blakemore, S.-J., & Decety, J. (2001). From the perception of action to the understanding of intention. *Nature Reviews Neuroscience*, *2*, 561-567.
- Botzung, A., Denkova, E., & Manning, L. (2008). Experiencing past and future personal events: Functional neuroimaging evidence on the neural bases of mental time travel. *Brain & Cognition*, *66*, 202-212.
- Brett, M. (1999). The MNI brain and the Talairach Atlas. <http://www.mrc-cbu.cam.ac.uk/Imaging/mnispac.html>.
- Bruner, J. (1986). *Actual minds, possible worlds*. Cambridge: Harvard University Press.
- Buckner, R. L., & Carroll, D. C. (2007). Self-projection and the brain. *Trends in Cognitive Sciences*, *11*, 49-57.

- 1
2
3
4
5
6
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44
45
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47
48
49
50
51
52
53
54
55
56
57
58
59
60
- Buckner, R. L., Snyder, A. Z., Shannon, B. J., LaRossa, G., Sachs, R., Fotenos, A. F., Sheline, Y. I., Klunk, W. E., Mathis, C. A., Morris, J. C., & Mintun, M. A. (2005). Molecular, structural, and functional characterization of Alzheimer's disease: Evidence for a relationship between default activity, amyloid, and memory. *Journal of Neuroscience*, *25*, 7709-7717.
- Buckner, R., Andrews-Hanna, J., & Schacter, D. (in press). The brain's default network: Anatomy, function and relevance to disease. *Annals of the New York Academy of Sciences*.
- Burgess, P. W., Scott, S. K., & Frith, C. D. (2003). The role of the rostral frontal cortex (area 10) in prospective memory: a lateral versus medial dissociation. *Neuropsychologia*, *41*, 906-918.
- Byrne, R., & Whiten, A. (1988). *Machiavellian intelligence: Social expertise and the evolution of intellect in monkeys, apes, and humans*. Oxford: Clarendon Press.
- Cabeza, R., Prince, S. E., Daselaar, S. M., Greenberg, D. L., Budde, M., Dolcos, F., LaBar, K. S., Rubin, D. C. (2004). Brain activity during episodic retrieval of autobiographical and laboratory events: An fMRI study using a novel photo paradigm. *Journal of Cognitive Neuroscience*, *16*, 1583-1594.
- Cabeza, R., & St Jacques, P. (2007). Functional neuroimaging of autobiographical memory. *Trends in Cognitive Sciences*, *11*, 219-227.
- Carruthers, P., & Smith, P. K. (1996). *Theories of theories of mind*. Cambridge: Cambridge University Press.
- Castelli, F., Frith, C., Happe, F., & Frith, U. (2002). Autism, Asperger syndrome and brain mechanisms for the attribution of mental states to animated shapes. *Brain*, *125*, 1839-1849.

- 1
2
3 Christoff, K., Geddes, L. M. T., & Gabrieli, J. D. E. (2001). Rostrolateral prefrontal
4 cortex involvement in evaluating self-generated information. *Neuroimage*, *13*,
5 S649-S649.
6
7
8
9
10 Cox, R. (1996). AFNI: Software for analysis and visualization of functional magnetic
11 resonance neuroimages. *Computational Biomedical Research*, *29*, 162–173.
12
13
14 Craik, F. I. M., Moroz, T. M., Moscovitch, M., Stuss, D. T., Winocur, G., Tulving, E., &
15 Kapur, S. (1999). In search of the self: A positron emission tomography study.
16 *Psychological Science*, *10*, 26-34.
17
18
19
20 D'Argembeau, A., Ruby, P., Collette, F., Degueldre, C., Balteau, E., Luxen, A., Maquet,
21 P., & Salmon, E. (2007). Distinct regions of the medial prefrontal cortex are
22 associated with self-referential processing and perspective taking. *Journal of*
23 *Cognitive Neuroscience*, *19*, 935-944.
24
25
26
27
28
29 D'Argembeau, A., Xue, G., Lu, Z.-L., Van der Linden, M. & Bechara, A. (in press).
30 Neural correlates of envisioning emotional events in the near and far future.
31 *Neuroimage*.
32
33
34
35
36 D'Esposito, M., Postle, B. R., Ballard, D., & Lease, J. (1999). Maintenance versus
37 manipulation of information held in working memory: An event-related fMRI
38 study. *Brain and Cognition*, *41*, 66-86.
39
40
41
42 D'Argembeau, A., & Van der Linden, M. (2004). Phenomenal characteristics associated
43 with projecting oneself back into the past and forward into the future: Influence of
44 valence and temporal distance. *Consciousness & Cognition*, *13*, 844–858.
45
46
47
48 de Vries, B., & Watt, D. (1996). A lifetime of events: Age and gender variations in the
49 life story. *International Journal of Aging & Human Development*, *42*, 81–102.
50
51
52
53 Dolan, R. J., & Frith, C. D. (2004). Empathy for pain involves affective but not sensory
54 components of pain. *Science*, *303*, 1157-1162.
55
56
57
58
59
60

- 1
2
3 Dunbar, R. I. M. (1993): Coevolution of neocortical size, group size and language in
4
5 humans. *Behavioral and Brain Sciences*, 16, 681–735.
6
7
8 Eichenbaum, H. (2000). A cortical-hippocampal system for declarative memory. *Nature*
9
10 *Reviews Neuroscience*, 1, 41–50.
11
12 Farah, M.J. (1989). The neural basis of mental imagery. *Trends in Neurosciences*, 12,
13
14 395-399.
15
16 Flinn, M. V., Geary, D. C., & Ward, C. V. (2005). Ecological dominance, social
17
18 competition, and coalitionary arms races: Why humans evolved extraordinary
19
20 intelligence. *Evolution and Human Behavior*, 26, 10-46.
21
22
23 Gallagher, H. L., & Frith, C. D. (2003). Functional imaging of 'theory of mind'. *Trends in*
24
25 *Cognitive Sciences*, 7, 77-83.
26
27
28 Garfield, J. L., Peterson, C. C., & Perry, T. (2001). Social cognition, language
29
30 acquisition, and the development of theory of mind. *Mind & Language*, 16, 494–
31
32 541.
33
34 Gilbert, S.J., Simons, J.S., Frith, C.D., & Burgess, P.W. (2006). Performance-related
35
36 activity in medial rostral prefrontal cortex (Area 10) during low-demand tasks.
37
38 *Journal of Experimental Psychology-Human Perception and Performance*, 32, 45-
39
40 48.
41
42
43 Gilboa, A. (2004). Autobiographical and episodic memory - one and the same? Evidence
44
45 from prefrontal activation in neuroimaging studies. *Neuropsychologia*, 42, 1336-
46
47 1349.
48
49
50 Greicius, M.D., Krasnow, B., Reiss, A.L., & Menon, V. (2003). Functional connectivity
51
52 in the resting brain: A network analysis of the default mode hypothesis.
53
54 *Proceedings of the National Academy of Sciences of the USA*, 100, 253-258.
55
56
57 Gusnard, D. A., Akbudak, E., Shulman, G. L., & Raichle, M. E. (2001). Medial
58
59 prefrontal cortex and self-referential mental activity: Relation to a default mode of
60

- 1
2
3 brain function. *Proceedings of the National Academy of Sciences of the United*
4
5
6 *States of America*, 98, 4259-4264.
- 7
8 Hassabis, D., Kumaran, D. & Maguire, E.A. (2007). Using imagination to understand the
9
10 neural basis of episodic memory. *Journal of Neuroscience*, 27, 14365-14374.
- 11
12 Hassabis, D., Kumaran, D., Vann, S. D., & Maguire, E. A. (2007). Patients with
13
14 hippocampal amnesia cannot imagine new experiences. *Proceedings of the*
15
16 *National Academy of Sciences of the United States of America*, 104, 1726-1731.
- 17
18 Hassabis, D., & Maguire, E. A. (2007). Deconstructing episodic memory with
19
20 construction. *Trends in Cognitive Sciences*, 11, 299-306
- 21
22
23 Humphrey, N. (1976). The social function of intellect. In P. Bateson & R. Hinde (Eds.),
24
25 *Growing points in ethology* (pp. 303-317). Cambridge: Cambridge University
26
27 Press.
- 28
29 Hutchinson, M., Schiffer, W., Joseffer, S., Liu, A., Schlosser, R., Dikshit, S., Goldberg,
30
31 E., Brodie, J.D. (1999). Task-specific deactivation patterns in functional magnetic
32
33 resonance imaging. *Magnetic Resonance Imaging*, 17, 1427-1436.
- 34
35
36 Johnson, S. C., Baxter, L. C., Wilder, L. S., Pipe, J. G., Heiserman, J. E., & Prigatano, G.
37
38 P. (2002). Neural correlates of self-reflection. *Brain*, 125, 1808-1814.
- 39
40 Kampe, K.K.W., Frith, C.D., & Frith, U. (2003). "Hey John": Signals conveying
41
42 communicative intention toward the self activate brain regions associated with
43
44 "mentalizing," regardless of modality. *Journal of Neuroscience*, 23, 5258-5263.
- 45
46
47 Keen, S. (2007). *Empathy and the novel*. New York: Oxford University Press.
- 48
49 Laird, A. R., Fox, P. M., Price, C. J., Glahn, D. C., Uecker, A. M., Lancaster, J. L.,
50
51 Turkeltaub, P. E., Kochunov, P., & Fox, P. T. (2005). ALE meta-analysis:
52
53 Controlling the false discovery rate and performing statistical contrasts. *Human*
54
55 *Brain Mapping*, 25, 155-164.
- 56
57
58
59
60

- 1
2
3 Laird, A. R., McMillan, K. M., Lancaster, J. L., Kochunov, P., Turkeltaub, P. E., Pardo,
4 J. V., & Fox, P. T. (2005). A comparison of label-based review and ALE meta-
5 analysis in the stroop task. *Human Brain Mapping, 25*, 6-21.
6
7
8
9
10 Larocque, L., & Oatley, K. (2006). Joint plans, emotions, and relationships: A diary study
11 of errors. *Journal of Cultural and Evolutionary Psychology, 4*, 245-265.
12
13
14 Levine, B., Freedman, M., Dawson, D., Black, S., & Stuss, D. T. (1999). Ventral frontal
15 contribution to self-regulation: Convergence of episodic memory and inhibition.
16 *Neurocase, 5*, 263-275.
17
18
19
20 Maguire, E. A. (1997). Hippocampal involvement in human topographical memory:
21 evidence from functional imaging. *Philosophical Transactions of the Royal*
22 *Society of London Series B-Biological Sciences, 352*, 1475-1480.
23
24
25
26
27 Maguire, E.A., Frackowiak, R.S.J., & Frith, C.D. (1996). Learning to find your way: A
28 role for the human hippocampal formation. *Proceedings of the Royal Society of*
29 *London Series B-Biological Sciences, 263*, 1745-1750.
30
31
32
33
34 Maguire, E.A., & Frith, C.D. (2003). Lateral asymmetry in the hippocampal response to
35 the remoteness of autobiographical memories. *Journal of Neuroscience, 23*, 5302-
36 5307.
37
38
39
40 Mar, R.A. (2004). The neuropsychology of narrative: story comprehension, story
41 production and their interrelation. *Neuropsychologia, 42*, 1414-1434.
42
43
44 Mar, R.A., & Oatley, K. (in press). The function of fiction is the abstraction and
45 simulation of social experience. *Perspectives on Psychological Science*.
46
47
48
49 Mar, R.A., Oatley, K., Hirsh, J., dela Paz, J., & Peterson, J. B. (2006). Bookworms versus
50 nerds: Exposure to fiction versus non-fiction, divergent associations with social
51 ability, and the simulation of fictional social worlds. *Journal of Research in*
52 *Personality, 40*, 694-712.
53
54
55
56
57
58
59
60

- 1
2
3 Markowitsch, H.J., Vandekerckhove, M.M.P., Lanfermann, H., & Russ, M.O. (2003).
4
5 Engagement of lateral and medial prefrontal areas in the ecphory of sad and happy
6
7 autobiographical memories. *Cortex*, 39, 643-665.
8
9
10 Mason, M. F., Norton, M. I., Van Horn, J. D., Wegner, D. M., Grafton, S. T., & Macrae,
11
12 C. N. (2007). Wandering minds: The default network and stimulus-independent
13
14 thought. *Science*, 315, 393-395.
15
16
17 McGuire, P. K., Paulesu, E., Frackowiak, R. S. J., & Frith, C. D. (1996). Brain activity
18
19 during stimulus independent thought. *Neuroreport*, 7(13), 2095-2099.
20
21
22 Mitchell, J. P., Banaji, M. R., & Macrae, C. N. (2005). The link between social cognition
23
24 and self-referential thought in the medial prefrontal cortex. *Journal of Cognitive*
25
26 *Neuroscience*, 17, 1306-1315.
27
28
29 Mitchell, J.P., Macrae, C.N., & Banaji, M.R. (2006). Dissociable medial prefrontal
30
31 contributions to judgments of similar and dissimilar others. *Neuron*, 50, 655-663.
32
33
34 Moscovitch, M., Nadel, L., Winocur, G., Gilboa, A., & Rosenbaum, R. S. (2006). The
35
36 cognitive neuroscience of remote episodic, semantic and spatial memory. *Current*
37
38 *Opinion in Neurobiology*, 16, 179-190.
39
40
41 Northoff, G., & Bermpohl, F. (2004). Cortical midline structures and the self. *Trends in*
42
43 *Cognitive Sciences*, 8, 102-107.
44
45
46 Oatley, K. (1999). Why fiction may be twice as true as fact: fiction as cognitive and
47
48 emotional simulation. . *Review of General Psychology*, 3, 101-117.
49
50
51 Ochsner, K. N., Beer, J. S., Robertson, E. R., Cooper, J. C., Gabrieli, J. D. E., Kihlstrom,
52
53 J. F., & D'Esposito, M. (2005). The neural correlates of direct and reflected self-
54
55 knowledge. *Neuroimage*, 28, 797-814.
56
57
58 Okuda, J., Fujii, T., Ohtake, H., Tsukiura, T., Tanji, K., Suzuki, K., Kawashima, R.,
59
60 Fukuda, H., Itoh, M., & Yamadori, A. (2003). Thinking of the future and past:

- 1
2
3 The roles of the frontal pole and the medial temporal lobes. *Neuroimage*, 19,
4 1369-1380.
5
6
7
8 Palmer, A. (2004). *Fictional minds*. Nebraska: University of Nebraska Press.
9
10 Parslow, D.M., Rose, D., Brooks, B., Fleminger, S., Gray, J.A., Giampietro, V.,
11 Brammer, M.J., Williams, S., Gasston, D., Andrew, C., Vythelingum, G.N.,
12 Loannou, G., Simmons, A., & Morris, R.G. (2004). Allocentric spatial memory
13 activation of the hippocampal formation measured with fMRI. *Neuropsychology*,
14 18, 450-461.
15
16
17
18
19
20 Perner, J. (2000). Memory and theory of mind. In F. I. M. Craik & E. Tulving (Eds.),
21 *Oxford Handbook of Memory* (pp. 297-312). New York: Oxford University Press.
22
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60
- The roles of the frontal pole and the medial temporal lobes. *Neuroimage*, 19, 1369-1380.
- Palmer, A. (2004). *Fictional minds*. Nebraska: University of Nebraska Press.
- Parslow, D.M., Rose, D., Brooks, B., Fleminger, S., Gray, J.A., Giampietro, V., Brammer, M.J., Williams, S., Gasston, D., Andrew, C., Vythelingum, G.N., Loannou, G., Simmons, A., & Morris, R.G. (2004). Allocentric spatial memory activation of the hippocampal formation measured with fMRI. *Neuropsychology*, 18, 450-461.
- Perner, J. (2000). Memory and theory of mind. In F. I. M. Craik & E. Tulving (Eds.), *Oxford Handbook of Memory* (pp. 297-312). New York: Oxford University Press.
- Peskin, J., & Astington, J. W. (2004). The effects of adding metacognitive language to story texts. *Cognitive Development*, 19, 253-273.
- Platek, S.M., Keenan, J.P., Gallup, G.G., & Mohamed, F.B. (2004). Where am I? The neurological correlates of self and other. *Cognitive Brain Research*, 19, 114-122.
- Raichle, M. E., & Gusnard, D. A. (2005). Intrinsic brain activity sets the stage for expression of motivated behavior. *Journal of Comparative Neurology*, 493, 167-176.
- Raichle, M. E., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A., & Shulman, G. L. (2001). A default mode of brain function. *Proceedings of the National Academy of Sciences of the United States of America*, 98, 676-682.
- Rosenbaum, R. S., Priselac, S., Kohler, S., Black, S. E., Gao, F. Q., Nadel, L., & Moscovitch, M. (2000). Remote spatial memory in an amnesic person with extensive bilateral hippocampal lesions. *Nature Neuroscience*, 3, 1044-1048.
- Rosenbaum, R.S., Stuss, D.T., Levine, B., & Tulving, E. (2007). Theory of mind is independent of episodic memory. *Science*, 318, 1257.

- 1
2
3 Schacter, D., & Addis, D. (2007). The cognitive neuroscience of constructive memory:
4 remembering the past and imagining the future. *Philosophical Transactions of the*
5 *Royal Society B-Biological Sciences*, 362, 773-786.
6
7
8
9
10 Schacter, D., Addis, D., & Buckner, R. (2007). Remembering the past to imagine the
11 future: the prospective brain. *Nature Reviews Neuroscience*, 8, 657-661.
12
13
14 Schacter, D.L., Addis, D.R., & Buckner, R. (in press). Episodic simulation of future
15 events: Concepts, data and applications. *Annals of the New York Academy of*
16 *Sciences*.
17
18
19
20
21 Sharot, T., Riccardi, A.M., Raio, C.M., & Phelps, E.A. (2007). Neural mechanisms
22 mediating optimism bias. *Nature*, 450, 102-105.
23
24
25 Spiers, H. J., & Maguire, E. A. (2007). The neuroscience of remote spatial memory: A
26 tale of two cities. *Neuroscience*, 149, 7-27.
27
28
29 Spreng, R. N., & Levine, B. (2006). The temporal distribution of past and future
30 autobiographical events across the lifespan. *Memory & Cognition*, 34, 1644 –
31 1651.
32
33
34
35
36 Squire, L. R., & Zola-Morgan, S. (1991). The medial temporal lobe memory system.
37 *Science*, 253, 1380 – 1386.
38
39
40 Stich, S., & Nichols, S. (1992). Folk psychology: Simulation or tacit theory? *Mind &*
41 *Language*, 7, 35–71.
42
43
44
45 Suddendorf, T., & Corballis, M.C. (1997). Mental time travel and the evolution of the
46 human mind. *Genetic Social and General Psychology Monographs*, 123, 133-167.
47
48
49 Suddendorf, T., & Corballis, M.C. (2007). The evolution of foresight: What is mental
50 time travel and is it unique to humans? *Behavioral and Brain Sciences*, 30, 299-
51 351.
52
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56
57
58
59
60

- 1
2
3 Sugiura, M., Friston, K.J., Willmes, K., Shah, N.J., Zilles, K., & Fink, G.R. (2007).
4
5 Analysis of intersubject variability in activation: An application to the incidental
6
7 episodic retrieval during recognition test. *Human Brain Mapping*, 28, 49-58.
8
9
10 Svoboda, E., McKinnon, M. C., & Levine, B. (2006). The functional neuroanatomy of
11
12 autobiographical memory: A meta-analysis. *Neuropsychologia*, 44, 2189-2208.
13
14 Szpunar, K. K., Watson, J. M., & McDermott, K. B. (2007). Neural substrates of
15
16 envisioning the future. *Proceedings of the National Academy of Sciences of the*
17
18 *United States of America*, 104, 642-647.
19
20
21 Talairach, J., & Tournoux, P. (1988). *Co-planar stereotaxic atlas of the human brain*.
22
23 New York: Thieme Medical Publishers.
24
25 Tulving, E. (1985). Memory and consciousness. *Canadian Psychology*, 26, 1-12.
26
27 Turkeltaub, P. E., Eden, G. F., Jones, K. M., & Zeffiro, T. A. (2002). Meta-analysis of the
28
29 functional neuroanatomy of single-word reading: Method and validation.
30
31 *Neuroimage*, 16, 765-780.
32
33
34 Wager, T. D., Lindquist, M., & Kaplan, L. (2007). Meta-analysis of functional
35
36 neuroimaging data: current and future directions. *Social Cognitive and Affective*
37
38 *Neuroscience*, 2, 150-158.
39
40
41 Walter, H., Adenzato, M., Ciaramidaro, A., Enrici, I., Pia, L., & Bara, B.G. (2004).
42
43 Understanding intentions in social interaction: The role of the anterior paracingulate
44
45 cortex. *Journal of Cognitive Neuroscience*, 16, 1854-1863.
46
47
48 Wheeler, M. A., Stuss, D. T., & Tulving, E. (1997). Toward a theory of episodic
49
50 memory: The frontal lobes and autonoetic consciousness. *Psychological Bulletin*,
51
52 121, 331-354.
53
54
55 Zunshine, L. (2006). *Why we read fiction: Theory of mind and the novel*. Columbus: Ohio
56
57
58
59
60 State University Press.

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6 Figure 1: ALE meta-analysis maps for individual domains demonstrating significant
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8 concordance across studies ($p < .05$ corrected for multiple comparisons). ABM =
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10 Autobiographical memory, NAV = Navigation, TOM = Theory-of-mind, DFM = Default
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12 mode, PRO = prospection. Images follow radiological convention: Left side of the brain
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14 is right.
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20 Figure 2: Conjunction between ALE maps of four domains. Red and yellow demarcate
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22 conjunction between two and three domains, respectively. The encapsulated black voxel
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24 (1 cm^2) indicates overlap across all four domains. Coronal coordinates for the panel slices
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26 are: A: $Y = 51$; B: $Y = -64$. Images follow radiological convention: Left is right. Sagittal
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28 coordinates of the left hemisphere panel slices are: C: $X = -4$; D: $X = -27$; E: $X = -48$.
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Table Captions

Table 1: AB = autobiographical, SMR = semantic memory retrieval, PSK = personal semantic knowledge, fMRI = functional magnetic resonance imaging, PET = positron emission tomography, ROI = region of interest.

Table 2: MN = mental navigation, VE = virtual environment, PM = passive movement, AV = attentive viewing.

Table 3: ToM = theory-of-mind.

Table 4: SIT = stimulus independent thought, Multiple Experimental Conditions A include visual, calculation, imagery, language, and perception processing. Multiple Experimental Conditions B comprises spatial, intentional, pleasantness and belief judgments, and perception of gaze. MA = meta-analysis

Tables 6–10: ALE meta-analysis results demonstrating significant concordance across studies ($p < .05$ corrected for multiple comparisons). Higher ALE value indicates greater concordance. Coordinates are reported according to the Talairach & Tournoux (1988) atlas. ALE = Activation likelihood estimation, Vol = cluster volume, L = Left, R = Right. † = Clusters greater than 10mm away from any other domain's clusters.

* = Brain region (BA) showed no ipsilateral correspondence with any other domain.

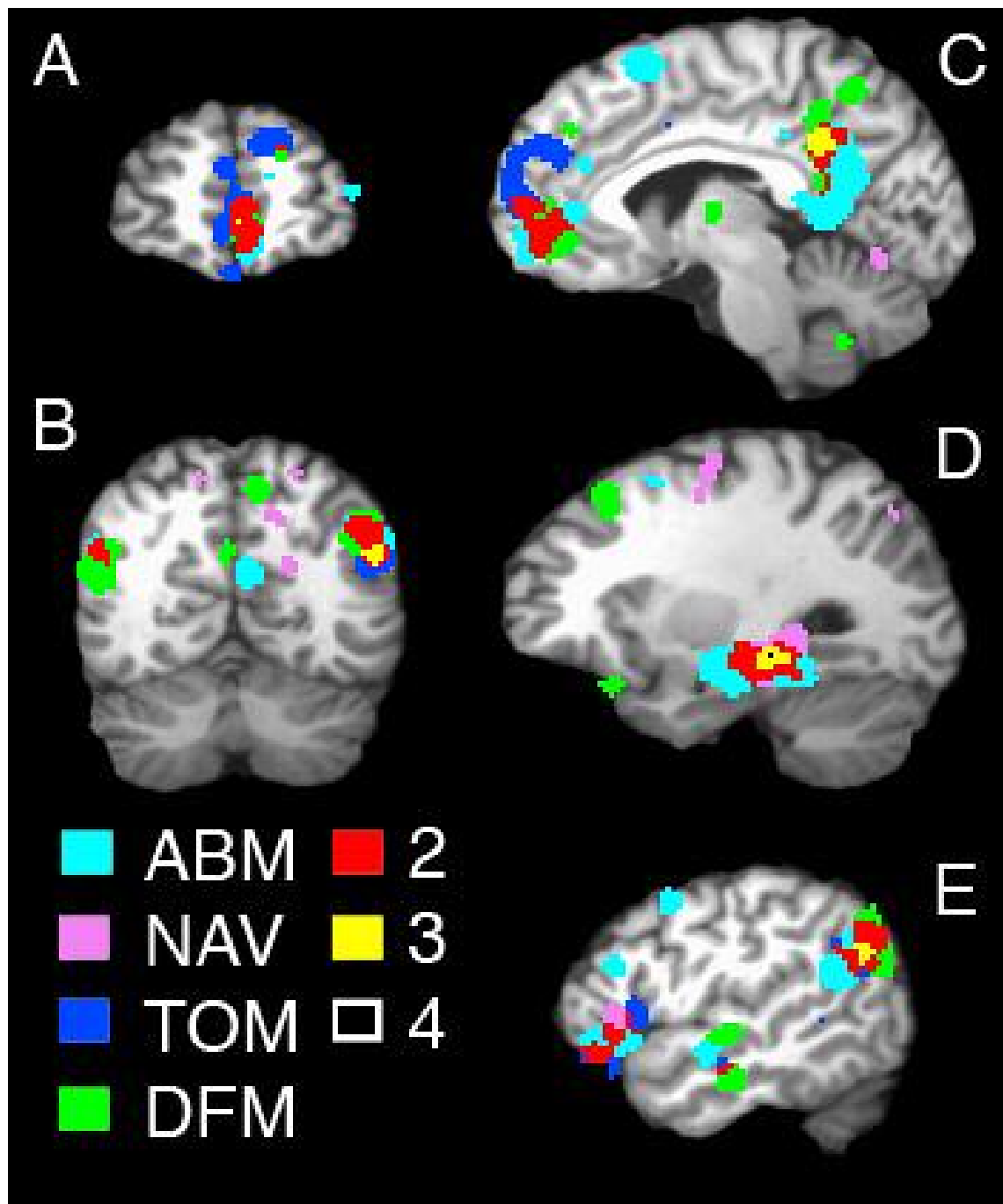
Note: Some unique clusters (†) were within 10mm of another domain's cluster, but never within the same BA. Some brain regions with no ipsilateral convergence (*) fell within 10mm of another domain's clusters but never within the same BA.

Anatomical Abbreviations: AMG = Amygdala, dACC = dorsal anterior cingulate cortex, HC = Hippocampus, MTG = Middle temporal gyrus, Occ = Occipital lobe, PHC = Parahippocampal cortex, PCC = posterior cingulate cortex, PCu = Precuneus, rACC =

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3 rostral anterior cingulate cortex, RSC = Retrosplenial cortex, STS = Superior temporal
4 sulcus, TPJ = Temporoparietal junction.
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10 Table 11: L = Left hemisphere cluster, R = Right hemisphere cluster, rACC = rostral
11 anterior cingulate gyrus, HC = Hippocampus, PHC = Parahippocampal cortex, AMG =
12 Amygdala, PCu/PCC = Precuneus & Posterior cingulate cortex, RSC = Retrosplenial
13 cortex, STS/MTG = Superior temporal sulcus & Middle temporal gyrus, Occ = Occipital
14 lobe.
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Figure 2: Conjunction across autobiographical memory, navigation, theory-of-mind and default mode.



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Table 1: Autobiographical memory data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Addis, DR, et al. (2004). <i>Hippocampus</i> , 14, 752-762.	Cued recall from pre-scan interview	Sentence completion, size discrimination	fMRI	14	16	
Andreasen, NC, et al. (1995). <i>American Journal of Psychiatry</i> , 152, 1576-1585.	Described personal past events	SMR	PET	13	7	
Denkova, E, et al. (2006). <i>Neuropsychologia</i> , 44, 2783-2791.	Cued recall using famous names	SMR	fMRI	12	15	
Denkova, E, et al. (2006). <i>Brain Research</i> , 1078, 143-150.	Cued recall using old photos	SMR	fMRI	10	26	
Fink, GR, et al. (1996). <i>Journal of Neuroscience</i> , 16, 4275-4282.	Listening to AB information	Listening to stranger's information	PET	7	5	
Gilboa, A, et al. (2004). <i>Cerebral Cortex</i> , 14, 1214-1225.	Cued recall using photos of self	Imagined event from stranger's photo	fMRI	9	5	
Graham, KS, et al. (2003). <i>Cognitive, Affective, & Behavioral Neuroscience</i> , 3, 234-254.	Cued recall using concepts (nouns)	SMR	PET	24	10	
Greenberg, DL, et al. (2005). <i>Neuropsychologia</i> , 43, 659-674.	Cued recall using pre-assigned cues	SMR	fMRI	11	18	

Table 1 continued: Autobiographical memory data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Levine, B, et al. (2004). <i>Journal of Cognitive Neuroscience</i> , 16, 1633-1646.	Cued recall using AB audio recordings	PSK, SMR, other's recordings	fMRI	5	14	
Maddock, RF, et al. (2001). <i>Neuroscience</i> , 104, 667-676.	Cued recall using familiar names	SMR	fMRI	8	24	
Maguire, EA, & Mummery, CJ (1999). <i>Hippocampus</i> , 9, 54-61.	True/False judgments for AB sentences	Listening to words, syllable counting	PET	8	8	
Maguire, EA, et al. (2000). <i>Hippocampus</i> , 10, 475-482.	True/False judgments for AB sentences	Listening to words, syllable counting	fMRI	6	9	
Maguire, EA, & Frith, CD (2003). <i>Brain</i> , 126, 1511-1523.	True/False judgments for AB sentences	SMR	fMRI	12	4	young adults
<i>ibid.</i>	True/False judgments for AB sentences	Listening to words, syllable counting	fMRI	12	5	older adults
Markowitsch, HJ, et al. (2000). <i>Behavioural Neurology</i> , 12, 181-190.	Listening to AB information	Listened to fictitious information	PET	8	8	
Piefke, M, et al. (2003). <i>Brain</i> , 126, 650-668.	Cued recall using AB sentences	Reading	fMRI	20	18	

Table 1 continued: Autobiographical memory data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Rekkas, PV & Constable, RT (2005). <i>Journal of Cognitive Neuroscience</i> , 17, 1950-1961.	Cued recall for recent past	SMR	fMRI	12	24	
Tsukiura, T, et al. (2003). <i>Neuroreport</i> , 14, 658-658.	Cued recall for recent past	SMR	PET	9	8	
Vandekerckhove, MMP, et al. (2005). <i>Behavioural Neurology</i> , 16, 203-210.	Cued recall using AB sentences	Item visualization	fMRI	16	18	
Viard, A, et al. (2007). <i>Cerebral Cortex</i> , 17, 2453-2467.	Cued recall using AB sentences	Letter detection	fMRI	12	7	older adults
			total	228	249	

Table 2: Navigation data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Avila, C, et al. (2006). <i>American Journal of Neuroradiology</i> , 27, 498-503.	Hometown-walking task	Number counting	fMRI	12	11	
Ghaem, O, et al. (1997). <i>Neuroreport</i> , 8, 739-744.	Mental simulation of routes	Mental visualization of landmarks	PET	5	3	
Hartley, T, et al. (2003). <i>Neuron</i> , 37, 877-888.	Wayfinding in VE	Trail following in VE	fMRI	16	8	
Iaria, G, et al. (2007). <i>European Journal of Neuroscience</i> , 25, 890-899.	Wayfinding in VE	Trail following in VE	fMRI	9	19	
Jordan, K, et al. (2004). <i>Neuroreport</i> , 15, 135-140.	Wayfinding in VE	PM, cued route, AV in VE	fMRI	8	15	
Kumaran, D & Maguire, EA. (2005). <i>Journal of Neuroscience</i> , 25, 7254-7259.	MN between friends' houses	Social relational task	fMRI	18	8	
Maguire, EA, et al. (1997). <i>Journal of Neuroscience</i> , 17, 7103-7110.	Mental simulation of routes	Number repetition	PET	11	11	
Maguire, EA, et al. (1998). <i>Science</i> , 280, 921-924.	Wayfinding in VE	Trail following in VE	PET	10	10	

Table 2 continued: Navigation data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Mayes, AR, et al (2004). <i>Neuropsychology</i> , 18, 426-441.	MN of newly learned route	Recall newly learned word definition	fMRI	9	7	
Mellet, E, et al. (2002). <i>Cerebral Cortex</i> , 12, 1322-1330.	Mental simulation of routes	Word pair counting	PET	6	12	
Pine, DS, et al. (2002). <i>Neuroimage</i> , 15, 396-406.	Wayfinding in VE	Trail following in VE	fMRI	20	27	10 adults, 10 adolescents
Rosenbaum, RS, et al. (2004). <i>Hippocampus</i> , 14, 826-835.	Mental simulation of routes	Vowel counting	fMRI	10	7	
Spiers, HJ & Maguire, EA. (2006). <i>Neuroimage</i> , 31, 1826-1840.	Customer-driven route planning in VE	Coasting	fMRI	20	13	
			total	154	151	

Table 3: Theory-of-mind data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Aichhorn, M., et al. (2006). <i>Neuroimage</i> , 30 , 1059-1068.	Adopted perspective of other	Perspective of self	fMRI	18	3	
Berthoz, S., et al. (2002). <i>Brain</i> , 125, 1696-1708.	Intentional social violation story	Unintentional social violation story	fMRI	12	10	
Bhatt, M., & Camerer, C.F. (2005). <i>Games & Economic Behavior</i> , 52 , 424-459.	Second-order belief judgment	Belief judgment	fMRI	16	2	
Brunet, E., et al. (2000). <i>Neuroimage</i> , 11 , 157-166.	Intention attribution	Physical causality attribution	PET	8	17	
Castelli, F, et al. (2000). <i>Neuroimage</i> , 12 , 314-325.	ToM animated shapes	Randomly moving shapes	PET	6	10	
Ferstl, E, & von Cramon, D (2002). <i>NeuroImage</i> , 17 , 1599-1612	Take perspective of person in sentences	Judged non-word sentences	fMRI	9	13	
Finger, E, et al. (2006). <i>NeuroImage</i> , 33 , 414-421	Moral or social transgression stories	Neutral stories	fMRI	16	2	
Fletcher, P, et al. (1995). <i>Cognition</i> , 57 , 109-128	ToM story judgement	Physical causation story judgement	PET	6	4	

Table 3 continued: Theory-of-mind data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Fukui, H, et al. (2006). <i>Neuroimage</i> , 32 , 913-920.	Competed against other in game	Played game independently	fMRI	16	2	
Gallagher, HL & Frith, CD (2004). <i>Neuropsychologia</i> , 42 , 1725-1736.	Expressive gestures	Instrumental gestures	fMRI	12	7	
German, TP, et al. (2004). <i>Journal of Cognitive Neuroscience</i> , 16 , 1805-1817.	Viewing pretense actions	Viewing real actions	fMRI	16	18	
Goel, V, et al. (1995). <i>Neuroreport</i> , 6 , 1741-1746.	Judge if Columbus could classify object	Simple classification of object	PET	10	4	
Grèzes, J, et al. (2004). <i>Journal of Neuroscience</i> , 24 , 5500-5505	Judged action as deceptive	Judged action as honest	fMRI	11	11	
Harris, LT, et al. (2005). <i>Neuroimage</i> , 28 , 763-769.	Internal attributions for behavior	Other attributions	fMRI	12	12	
Kobayashi, C, et al. (2006). <i>Brain and Language</i> , 98 , 210-220.	False belief tasks	Sentence previously presented	fMRI	32	7	16 bilinguals, 16 monolinguals
Mitchell, JP, et al. (2005). <i>Journal of Cognitive Neuroscience</i> , 17 , 1306-1315.	Form impression based on behavior	Remember sequence of information	fMRI	18	13	

Table 3 continued: Theory-of-mind data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Ohnishi, T, et al. (2004). <i>Neuroreport</i> , 15, 1483-1487.	ToM animated shapes	Randomly moving shapes	fMRI	10	13	adolescents
Perner, J, et al. (2006). <i>Social Neuroscience</i> , 1, 245-258	False belief stories	False photograph stories	fMRI	19	6	
Rilling, JK, et al. (2004). <i>Neuroimage</i> , 22, 1694-1703.	Competed against putative other in game	Button presses	fMRI	19	10	
Ruby, P & Decety, J (2003). <i>European Journal of Neuroscience</i> , 17, 2475-2480.	Adopted lay perspective	Perspective of self	PET	10	13	
Russell, T, et al. (2000). <i>American Journal of Psychiatry</i> , 157, 2040-2042	Judge mental state from face	Judge gender from face	fMRI	7	4	
Saxe, R & Kanwisher, N (2003). <i>Neuroimage</i> , 19, 1835-1842.	ToM story judgment	Physical causality story judgment	fMRI	25	5	
Saxe, R, et al. (2006). <i>Social Neuroscience</i> , 1, 284-298	False belief stories	False photograph stories	fMRI	12	8	
Saxe, R & Wexler, A (2005). <i>Neuropsychologia</i> , 43, 1391-1399	False belief stories	False photograph stories	fMRI	12	4	

Table 3 continued: Theory-of-mind data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Schilbach, L, et al. (2006). <i>Neuropsychologia</i> , 44 , 718-730.	View social interaction with self	View social interaction with other	fMRI	18	3	
Spiers, HJ & Maguire, EA. (2006). <i>Neuropsychologia</i> , 44 , 1674-1682.	Spontaneous ToM events	Non-ToM events	fMRI	20	1	
Vogeley, K, et al. (2001). <i>Neuroimage</i> , 14 , 170-181.	ToM story judgment	Non-ToM story judgments	fMRI	8	7	
Vollm, BA, et al. (2006). <i>Neuroimage</i> , 29 , 90-98.	ToM cartoon judgement	Physical causality cartoon judgement	fMRI	13	13	
Walter, H, et al. (2004). <i>Journal of Cognitive Neuroscience</i> , 16 , 1854-1863	Communicative intention	Physical causality attribution	fMRI	13	18	
<i>ibid</i>	Communicative intention	Physical causality attribution	fMRI	12	15	
Wicker, B, et al. (2003). <i>Neuropsychologia</i> , 41 , 139-146.	Intention attribution to direct gaze	Averted gaze	PET	10	1	
			total	416	255	

Table 4: Default mode data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Andreasen, NC, et al (1995) <i>American Journal of Psychiatry</i> , 152, 1576-1585.	Rest	Semantic memory retrieval	PET	13	7	
Binder, JR, et al. (1999). <i>Journal of Cognitive Neuroscience</i> , 11, 80-93.	Rest	Active listening	fMRI	30	8	
Christoff, K, et al. (2004). <i>Cortex</i> , 40, 623-630.	Rest	Arrow cued button press	fMRI	12	15	
D'Argembeau, A, et al. (2005). <i>Neuroimage</i> , 25, 616-624.	Rest	Reflecting on self, other and society	PET	12	9	
Fransson, P (2006). <i>Neuropsychologia</i> , 44, 2836-2845.	Rest	Working memory	fMRI	14	21	
Greicius, MD, et al. (2004). <i>Proceedings of the National Academy of Sciences</i> , 101, 4637-4642	Rest	Button press to flashing screen	fMRI	14	8	young adults
<i>ibid.</i>	Rest	Button press to flashing screen	fMRI	14	17	young adults
<i>ibid.</i>	Rest	Button press to flashing screen	fMRI	13	22	older adults

Table 4 continued: Default mode data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Gould, RL, et al. (2006). <i>Neuroimage</i> , 31, 818-831.	Rest	Paired associate retrieval and encoding	fMRI	24	18	12 young, 12 older adults
Kennedy, DP, et al. (2006). <i>Proceedings of the National Academy of Sciences</i> , 103, 8275-8280.	Fixation	Counting Stroop task	fMRI	14	8	
Mason, MF, et al. (2007). <i>Science</i> , 315, 393-395.	Rest	Working memory	fMRI	19	20	
Mazoyer, B, et al. (2001). <i>Brain Research Bulletin</i> , 54, 287-298.	Rest	Multiple Experimental Conditions A	PET	63	24	MA (9 studies)
McGuire, PK, et al. (1996). <i>Neuroreport</i> , 7, 2095-2099.	SITF	Articulation	PET	5	5	
<i>ibid.</i>	SITF	Reading	PET	6	1	ROI
McKiernan, KA, et al. (2003). <i>Journal of Cognitive Neuroscience</i> , 15, 394-408.	Rest	Target detection	fMRI	30	20	
Persson, et al. (2007). <i>Journal of Cognitive Neuroscience</i> , 19, 1021-1032.	Fixation	Verb generation	fMRI	60	11	32 young, 28 older adults

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Table 4 continued: Default mode data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Raichle, ME, et al. (2001). <i>Proceedings of the National Academy of Sciences</i> , 98, 676-682.	Rest	ROI regional/global brain oxygen flow	PET	19	6	ROI
<i>ibid.</i>	Rest	ROI regional/global brain oxygen flow	PET	19	7	ROI
Shulman, GL, et al. (1997). <i>Journal of Cognitive Neuroscience</i> , 9, 648-663.	Fixation	Visual information processing	PET	132	14	MA (9 studies)
Wicker, B, et al. (2003). <i>Brain Research Reviews</i> , 43, 224-230.	Rest	Multiple Experimental Conditions B	PET	42	6	MA (5 studies)
				<hr/>		
				total	555	247

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Table 5: Prospection data sources

Study	Task	Comparison Task	Modality	n	foci	Comments
Addis, et al. (2007). <i>Neuropsychologia</i> , 45 , 1363–1377	Cued future event elaboration	Imagery and semantic elaboration	fMRI	14	14	Coordinates provided by author
Botzung, et al. (2008). <i>Brain & Cognition</i> , 66 , 202-212.	Cued 'pre-experiencing' of previously determined event	Judgment of semantic relatedness	fMRI	10	12	
D'Argembeau, et al. (in press). <i>Neuroimage</i> , doi:10.1016/j.neuroimage.2007.11.025	Cued 'pre-experiencing' of previously determined event	Imagining routine activity	fMRI	12	6	
Okuda, et al. (2003). <i>NeuroImage</i> , 19, 1369–1380.	Talking about personal distant future	Talking about the meaning of words	PET	12	14	
Sharot, et al. (2007). <i>Nature</i> , 450 , 102-105.	Cued future event from short description	Fixation	fMRI	15	24	Coordinates provided by author
Szpunar, et al. (2007). <i>Proceedings of the National Academy of Sciences</i> , 104 , 642–647.	Cued future event of common life experience	Cued imagining of Bill Clinton	fMRI	21	16	Coordinates provided by author
			total	84	86	

Table 6: Autobiographical memory results

Extent of Cluster				Coordinates			ALE (10^{-3})	Vol (mm^3)
Laterality	Anatomic Region(s)	Brodmann Area(s)	x	y	z			
L & R	PCu, PCC	7, 31, 23	-2	-53	18	26.4	9256	
L	HC, PHC, AMG	35, 36, 28*	-25	-26	-14	27.0	7776	
L	TPJ	39, 22	-47	-61	26	19.6	3632	
L	Medial prefrontal cortex, rACC (bilateral)	10, 24, 32	-3	47	-1	20.8	2456	
L	STS, MTG, inferior temporal sulcus	20, 21	-56	-8	-14	22.8	2192	
L	Ventrolateral prefrontal cortex, temporal pole	47, 38	-47	25	-5	14.0	1664	
R	HC, PHC	36, 35, 28	23	-31	-12	20.8	1640	
† L & R	Middle frontal gyrus	6	-3	12	57	24.0	1448	
R	TPJ	39	49	-59	27	14.3	1136	
† L	Posterior lateral prefrontal cortex	6	-45	3	45	14.6	704	
† L	Frontal pole (lateral)	10	-40	47	14	16.8	672	

Table 6 continued: Autobiographical memory results

Extent of Cluster			Coordinates					
Laterality	Anatomic Region(s)	Brodmann Area(s)	x	y	z	ALE (10^{-3})	Vol (mm^3)	
R	HC, PHC	28	23	-13	-15	15.2	640	
R	Temporal pole, STS, MTG	38*, 21	49	-5	-13	11.8	608	
L	Temporal pole	38	-37	14	-32	14.2	584	
L	Occ	19	-37	-81	30	12.8	568	
†	L	Dorsolateral prefrontal cortex	46*, 45	-46	24	21	13.8	456
	R	Ventrolateral prefrontal cortex	47	50	27	-5	8.9	240
	L	Frontal pole (medial)	10	-11	55	17	9.8	184
	R	Thalamus	n/a	3	-9	5	9.3	184
	L	rACC	32	-5	33	22	10.7	168
	L	PCC	31	-6	-37	33	10.9	152
	L	Superior frontal sulcus	6	-28	9	51	9.6	144
	R	AMG	n/a	28	1	-19	10.1	104

Table 7: Navigation results

Extent of Cluster			Coordinates					
Laterality	Anatomic Region(s)	Brodmann Area(s)	x	y	z	ALE (10 ⁻³)	Vol (mm ³)	
R	HC, PHC	28, 27*, 35, 36	25	-30	-8	24.3	5928	
L	HC, PHC	27, 35, 36	-25	-34	-8	17.3	4440	
L	RSC, PCC	30, 31	-17	-58	21	20.2	1800	
L	TPJ, Occ	39, 19	-34	-78	34	13.9	1584	
R	RSC, PCC	30, 31	16	-54	17	13.4	1400	
R	TPJ, Occ	39, 19	42	-74	32	13.3	1168	
L	Ventrolateral prefrontal cortex	47, 45	-47	22	1	12.8	1104	
†	R	Superior frontal sulcus	6	27	-3	53	8.8	616
†	L	Superior frontal sulcus	6	-27	-11	55	9.5	448
†	R	Superior parietal lobule	7	13	-68	54	8.8	304
†	L	Cerebellar vermis	n/a*	-6	-69	-10	9.0	296

Table 7 continued: Navigation results

Extent of Cluster			Coordinates					
Laterality	Anatomic Region(s)	Brodmann Area(s)	x	y	z	ALE (10^{-3})	Vol (mm^3)	
L	PCu	7	-12	-62	39	8.4	264	
R	Thalamus	n/a	7	-6	7	8.8	264	
†	L	Ventral temporal lobe	20	-37	-8	-35	9.4	256
†	R	Posterior medial prefrontal cortex, dACC	6, 32	13	11	47	7.9	224
L	Superior parietal lobule	7	-20	-67	52	8.4	216	
L	Thalamus	n/a	-13	-24	8	9.0	208	

Table 8: Theory-of-mind results

Extent of Cluster			Coordinates				
Laterality	Anatomic Region(s)	Brodmann Area(s)	x	y	z	ALE (10^{-3})	Vol (mm^3)
L & R	Anterior medial prefrontal cortex, rACC	10, 9, 32	-3	52	20	20.9	7704
R	TPJ	39, 40*, 22	54	-49	19	22.9	6944
L	TPJ	39, 40*, 22	-54	-54	18	16.4	4168
R	Temporal pole, STS, MTG	38, 21, 20	54	-13	-13	17.1	3024
L	STS, MTG	21	-55	-17	-10	18.2	1752
L & R	PCu, PCC	7, 31	-4	-52	31	12.7	1000
L	Temporal pole, ventrolateral prefrontal cortex,	38, 47	-46	29	-11	20.3	888
R	Ventrolateral prefrontal cortex	45, 47	50	30	-3	12.1	824
L	Ventrolateral prefrontal cortex	45, 44, 47	-50	15	3	14.0	616
L	AMG	n/a	-25	-6	-20	15.4	592
†	R	Occ	34	-92	1	14.1	568

Table 8 continued: Theory-of-mind results

Extent of Cluster			Coordinates				
Laterality	Anatomic Region(s)	Brodmann Area(s)	x	y	z	ALE (10^{-3})	Vol (mm^3)
R	Dorsolateral prefrontal cortex	9, 8	23	46	39	13.9	472
R	AMG	n/a	24	1	-18	13.0	352
L & R	Ventromedial prefrontal cortex	11	3	50	-16	11.7	320
R	PCC, RSC	23, 29, 30	6	-57	15	12.5	312
L	Fusiform gyrus	37	-37	-44	-14	11.4	248
L	TPJ	39	-43	-68	39	12.1	248
L	HC, PHC	36	-30	-31	-9	10.2	224
† R	Occ	19	26	-97	14	9.2	176
† R	Insula	13	46	8	-4	10.8	160
† L & R	dACC	24	-1	4	37	10.3	112
L	PCu	7	-9	-51	42	9.7	112

Table 9: Default mode results

Extent of Cluster			Coordinates				
Laterality	Anatomic Region(s)	Brodmann Area(s)	x	y	z	ALE (10 ⁻³)	Vol (mm ³)
L & R	Medial prefrontal cortex, rACC	10, 11, 32	-1	47	-1	27.4	5976
L	TPJ, Occ	39, 19	-43	-69	32	28.4	4888
L	PCu, PCC, RSC	7, 31, 23, 30, 29	-7	-48	31	19.3	3152
R	TPJ, STS	39, 22	49	-63	20	22.2	2464
L	Insula, superior temporal gyrus, STS	13*, 22	-43	-19	-2	18.7	1464
L	Dorsal prefrontal cortex	9, 8*	-24	27	45	16.5	1408
R	Dorsal prefrontal cortex	9, 8	20	38	40	18.1	1240
L	Dorsal prefrontal cortex	8*	-12	42	39	12.0	784
L	PHC	36, 37, 35, 20	-26	-36	-13	12.4	776
L	Inferior temporal sulcus	20	-49	-18	-18	17.4	760
L	PCu	7	-6	-61	48	15.6	720

Table 9 continued: Default mode results

Extent of Cluster			Coordinates				
Laterality	Anatomic Region(s)	Brodmann Area(s)	x	y	z	ALE (10^{-3})	Vol (mm^3)
R	PCu, PCC	7, 31	6	-59	24	11.5	696
† R	Insula	13	40	-11	4	14.3	608
L	Ventral prefrontal cortex, temporal pole	47, 38	-29	24	-21	11.9	464
L	Frontal pole, dorsolateral prefrontal cortex	10, 9	-15	55	26	12.6	288
L	Thalamus	n/a	-3	-12	5	12.6	272
L	Inferior temporal sulcus, MTG	20, 21	-60	-15	-19	9.7	240
R	Inferior temporal sulcus, MTG	20, 21	62	-16	-17	11.0	240
† R	Cerebellum, pyramis	n/a *	41	-76	-33	10.5	232
† L	Cerebellum, inferior semi-lunar lobule	n/a *	-6	-58	-40	11.8	184
L	Superior lateral prefrontal cortex	8*	-35	20	50	10.1	128

Table 10: Prospection results

Extent of Cluster			Coordinates				
Laterality	Anatomic Region(s)	Brodmann Area(s)	x	y	z	ALE (10^{-3})	Vol (mm^3)
L & R	PCC, PCu	31, 23	-5	-51	29	16.8	2944
L & R	Anterior medial prefrontal cortex	10, 11	-1	59	-4	9.9	1536
L	TPJ	39	-49	-64	29	13.2	1136
L	HC, PHC, tail of caudate	37	-28	-41	-5	9.0	1024
L	Dorsolateral prefrontal cortex	9	-17	45	30	9.7	968
L & R	rACC, ventromedial prefrontal cortex (left only)	32, 11	-1	41	-12	7.7	608
L	STS, MTG	21, 20	-52	-7	-14	10.8	600
R	AMG, PHC	34, 28	21	-9	-13	11.6	600
R	RSC	30, 29	9	-54	9	9.0	496
R	HC, PHC	36	32	-28	-11	8.3	392
L	RSC	30, 29	-5	-53	12	7.0	112
L	rACC	32	-7	46	1	7.0	104

Table 11: Correspondence across domains

Domain	Prefrontal			Medial Temporal			Medial Parietal		Lateral		
	Pole	rACC	Lateral	HC	PHC	AMG	PCu/PCC	RSC	TPJ	STS/MTG	Occ
Autobiographical Memory	L	LR	LR	LR	LR	LR	LR	LR	LR	LR	L
Navigation	-	-	L	LR	LR	-	LR	LR	LR	-	LR
Theory of Mind	LR	LR	LR	L	L	LR	LR	R	LR	LR	R
Default Mode	LR	LR	L	-	L	-	LR	L	LR	LR	L
Prospection	LR	LR	L	LR	LR	R	LR	LR	L	L	-