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## Research Report

## Undirected thought: Neural determinants and correlates

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## ARTICLE INFO

## Article history:

Accepted 28 September 2011

Available online 8 October 2011

## Keywords:

Mind wandering  
Spontaneous thought  
Default network  
Executive network  
Memory network

## ABSTRACT

While goal-directed thinking has received the lion's share of neuroscientific attention, its counterpart—the undirected thought flow that comes to mind unbidden and without effort—has remained largely on the sidelines of scientific research. Such undirected thought, however, forms a large part of our mental experience. The last decade of neuroscientific investigations marked a resurgence of interest and work into the neural basis of undirected thought. This article reviews the current status of the field and examines the research on the three most frequently discussed categories of undirected thought: spontaneous thought, stimulus-independent thought, and mind wandering. The terminology and paradigms for investigating undirected thought are still being developed, while research is gradually moving beyond strictly task- and rest-based paradigms and towards incorporating introspective first-person reports in order to better understand this phenomenon. It is impossible to say at this point that undirected thinking is preferentially linked to any one particular brain system. Although its connection to the default network has been disproportionately emphasized in the literature, other brain networks such as the executive system and the temporal lobe memory network appear to be equally involved. In addition to reviewing the literature, this article also presents novel findings regarding the functional connectivity between large-scale brain networks during mind wandering. These findings reveal the presence of positive functional connectivity between regions of the default and executive networks and negative functional connectivity between the default network and primary sensory cortices. Thus, the default and executive networks can closely cooperate in supporting undirected thought processes, and seem to do so at times when the primary sensory cortices are not busy with the processing of perceptual information from the external environment.

*This article is part of a Special Issue entitled The Cognitive Neuroscience of Thought.*

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## 1. Introduction

Most people view thinking as a goal-directed phenomenon, or a mental process deliberately employed towards solving a problem or making progress on a task. In contrast, another much less dominant view has emphasized thinking's undirected, spontaneous nature—from William James' discussion of the thought's tendency to drift (James, 1980), to research on daydreaming

during the 1960s (Antrobus et al., 1966; Singer and Schonbar, 1961), to more recent research on spontaneous thought and mind wandering (Christoff et al., 2004, 2009a; Klinger and Cox, 1987; Smallwood and Schooler, 2006; Teasdale et al., 1995).

The last decade of neuroscientific investigations marked a resurgence of interest and work into the neural basis of undirected thought. The research is still in its infancy and there is no clear agreement about the most appropriate terminology to use. For example, is all daydreaming undirected? Is mind

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wandering the same as daydreaming? These questions remain unanswered. It is clear, however, that undirected thought forms a large part of our mental experience. Ninety-six percent of American adults report some kind of daydreaming each day (Singer and McCraven, 1961) and at least 30% of thoughts that people experience in their daily lives can be classified as mind wandering, as defined by their lack of relation to the current task (Kane et al., 2007; Killingsworth and Gilbert, 2011; Klinger and Cox, 1987). Furthermore, as many as 50% of thoughts can be classified as daydreaming, defined as a nonworking thought that was either spontaneous or fanciful (Klinger, 2009). Given this striking prevalence of undirected thought in our mental experience, it is clear that understanding its neuroscientific underpinnings is a necessary step towards improving our overall understanding of human thought.

The terms “spontaneous thought” (Christoff et al., 2004, 2011b) “stimulus-independent thought” (Gilbert et al., 2007; Mason et al., 2007a,b; McGuire et al., 1996), and “mind wandering” (Christoff et al., 2009a; Schooler et al., 2011; Smallwood and Schooler, 2006) have been used most frequently during the last decade of neuroscientific investigations. The term “task-unrelated thought” has also been used in the literature, largely overlapping with the way “mind wandering” has been operationally defined. All these terms are sometimes used interchangeably although they are by no means the same thing. Furthermore, the definition of each of these terms is often different across different researchers and sometimes even across different publications by the same researchers.

This terminological fluidity is understandable; the neuroscience of undirected thought is still in its infancy. To some extent such fluidity is useful in that it allows researchers to continue to improve their definitions as they learn more about the relevant phenomena. Partly because of this terminological uncertainty and partly because the experimental paradigms for its study are still developing, it is impossible to say at this point that undirected thinking is preferentially linked to any particular brain systems. A connection between undirected thought and the default network has been empirically demonstrated on a number of occasions (e.g., Christoff et al., 2009a; Mason et al., 2007b). However, other brain networks such as the executive system and the temporal lobe memory network appear to be equally involved (Christoff et al., 2004, 2009a; Stark and Squire, 2001).

This article reviews the three most frequently investigated forms of thought—spontaneous thought, stimulus-independent thought, and mind wandering—that are considered to be largely undirected. Almost all of neuroscientific investigations so far have used rest as an experimental paradigm to study undirected thought. During rest, subjects are simply instructed to do nothing. No experimental task is given to them, and they are typically presented with a blank screen in front of them while they are lying in the scanner. This minimizes the external perceptual and cognitive demands on subjects, and as behavioral research has consistently shown (Filler and Giambra, 1973; Giambra and Grodsky, 1989), conditions of low external demands result in high rate of undirected thoughts, such as daydreaming, mind wandering, or stimulus independent thought. However, the existence of such undirected thoughts during rest is only indirectly inferred. By contrast, using experience sampling—a procedure during which subjects are asked to report on the quality of their thought experience in an online fashion, as these thoughts

occur in the scanner—offers a more direct way of investigating undirected thought processes, but has only begun to be used very recently (Christoff et al., 2009a). As the field progresses, both experimental paradigms and terminology will undoubtedly become more sophisticated.

The term “undirected thought” is used here in the sense of “not deliberately directed” by the thinker, and in contrast to the usual way in which goal-directed thought is conceptualized. While undirected thought is not deliberately directed towards a particular goal or outcome, its direction may be implicitly biased or influenced by the thinker’s current concerns or emotional states. In that sense, undirected thought is not necessarily completely undirected—for example, spontaneous thought can be biased by making personality traits self-relevant (Smallwood et al., 2009, 2011) or by priming an individual’s “to do list” (Stawarczyk et al., 2011). However, the crucial feature of undirected thought is that it proceeds without the conscious, deliberate effort for channeling its course in particular direction on the part of the thinking person.

In addition to reviewing the current status of undirected thought research, this article also presents novel findings regarding the functional interactions between the default and executive network, on the one hand, and the primary sensory cortices, on the other hand. The functional interrelation between these large-scale brain networks during undirected thought is one of the most intriguing but as of yet largely unexamined research directions.

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## 2. Spontaneous thought

Spontaneous thought can be defined as the unintended, non-working, noninstrumental mental content that comes to mind unbidden and effortlessly (Klinger, 2009). What distinguishes spontaneous thoughts from deliberate thoughts is the way in which they occurred and the extent to which the thinker deliberately directs them (Klinger, 2009). Conceptually, spontaneous thought differs from mind wandering and stimulus-independent thought. For example, if mind wandering is defined as thinking that’s unrelated to the ongoing task or activity, then mind wandering can occur either spontaneously (as in when we catch our mind having wandered off during the last paragraph of whatever we were reading), or deliberately (as in when we decide to “tune out” during a boring lecture and instead direct our thoughts towards some future event of greater interest). Similarly, stimulus-independent thought—thinking about something that is unrelated to what we are currently perceiving—can also occur either spontaneously or deliberately.

In neuroscientific practice so far, spontaneous thought has only been examined in terms of the mental processes that occur during rest. During conditions of low external demands such as rest or a highly practiced task, individuals often report experiencing spontaneously arising thoughts and the contents of such spontaneous thoughts often have to do with personally significant or concerning events (Klinger and Cox, 1987; Singer, 1966). Assuming that the neural activations observed during rest conditions reflect to a large extent the occurrence of spontaneous cognition, investigators have identified a number of brain regions that appear to be preferentially linked to spontaneous thought, including midline default network regions (posterior

cingulate cortex/precuneus and anterior medial PFC), temporopolar cortex and medial temporal lobe structures (hippocampus and parahippocampus), and the RL PFC.

What role does each of these brain areas play in spontaneous thought? Researchers have hypothesized that activation of the posterior cingulate cortex (PCC) and the anterior medial PFC may reflect the affective, self-relevant nature of spontaneous thoughts (Andrews-Hanna et al., 2010). Medial PFC recruitment may also reflect acts of spontaneous mentalizing, i.e., imagining the thoughts and intentions of other individuals (Spiers and Maguire, 2006). The temporopolar cortex may also contribute to spontaneous mentalizing (Spiers and Maguire, 2006). By virtue of its anatomical connectivity with medial temporal lobe structures and its role in autobiographical memory (Graham et al., 2003), the temporopolar cortex may also participate in experiencing spontaneously arising memories (Christoff et al., 2004) especially those memories rich in sensory–perceptual detail (Conway, 2001).

The functional role of the precuneus is currently a subject for intense investigation, but findings are starting to converge to show that it plays an important role in episodic memory retrieval and self-related mental imagery during rest (Cavanna and Trimble, 2006). Similarly, the medial temporal lobe structures may contribute to spontaneously retrieved memories (Stark and Squire, 2001; Christoff et al., 2004; Gelbard-Sagiv et al., 2008) and the simulation of future events (Buckner, 2010).

Finally, the link between RL PFC and spontaneous thought may seem at first surprising, given extensive evidence from task-based paradigms that these brain regions are specifically involved in deliberate, meta-cognitive processes such as monitoring one's own internal cognitive states and higher order reasoning (Christoff and Gabrieli, 2000; Christoff et al., 2001, 2003; McCaig et al., 2011). The consistent RL PFC recruitment during rest (Christoff et al., 2004; Shulman et al., 1997) has been suggested to reflect the meta-cognitive evaluation and manipulation of self-generated thoughts (Christoff et al., 2004; Dumontheil et al., 2010). However, such evaluation and manipulation are generally considered to be deliberate, goal-oriented mental processes, and do not generally occur spontaneously. Instead, RL PFC's role in spontaneous thought may be more closely linked to the maintenance of an abstract mindset (Christoff and Keramatian, 2007; Christoff et al., 2009b), which may enable the spontaneous thought flow to occur uninterrupted by attention to our ongoing concrete (i.e., sensory and specific) perceptions.

It should be emphasized, however, that all these hypotheses regarding the role of different brain regions in spontaneous thought are based on indirect inferences and our knowledge of these regions' functions from task-based research. To further our knowledge of the neuroscience of spontaneous thought, it will be necessary to conduct direct empirical investigations in which subject's introspective reports about their spontaneously occurring thoughts, obtained in a trial-by-trial basis, can be linked to neural recruitment (Christoff et al., 2011a). This method, known as thought sampling (Christoff et al., 2004; Teasdale et al., 1993) or experience sampling (Christoff et al., 2009a; Kahneman et al., 2004), has not yet been utilized in the neuroscientific study of spontaneous thought.

### 3. Stimulus-independent thought

Within the context of cognitive neuroscience, the term stimulus-independent thought is sometimes used interchangeably with the term mind wandering (e.g., Mason et al., 2007a,b). However, the two are conceptually different. In general, stimulus-independent thought is easier to define than mind wandering. By definition, stimulus-independent thought is decoupled from current sensory information (Antrobus, 1968; Teasdale et al., 1993). This could occur in the form of mind wandering away from a task (Mason et al., 2007a,b), but it can also occur in the form of complex task-related thought that goes beyond the current sensory information (Gilbert et al., 2006a). Stimulus-independent thought is typically contrasted to stimulus-oriented thought, which reflects attention towards the current external sensory environment (Gilbert et al., 2006a; Ritter and Weber, 1973). Stimulus-oriented thought can involve watchfulness towards upcoming task-related stimuli but it can also occur in the form of mind wandering away from a task (e.g., paying attention to scanner noise or incidental light) (Gilbert et al., 2007). Thus, theoretically, stimulus-independent thought and mind wandering are independent dimensions of thought (Klinger, 2009) although in practice they do tend to be correlated in the sense that the majority of mind wandering tends to be decoupled from current sensory information.

Similarly to spontaneous thought, the neuroscientific study of stimulus-independent thought has come almost exclusively from brain recruitment during rest, although recently studies have also investigated this phenomenon from task perspective (Gilbert et al., 2006b) and using experience sampling (Vanhaudenhuyse et al., 2011). The medial PFC has received the most attention within this literature with a number of studies suggesting its involvement in stimulus-independent thought (Mason et al., 2007b; McGuire et al., 1996). Some researchers, however, have argued against this by using task-based paradigms to suggest that the medial PFC is involved in stimulus-oriented thought (Gilbert et al., 2006a, 2007). This controversy (Gilbert et al., 2007; Mason et al., 2007a,b) remains unresolved. Once again, the evidence so far only relies upon indirect inferences about the presence of stimulus-independent or stimulus-oriented thought based on the level of task requirements (e.g., stimulus-independent thought is more likely to occur during easier task-blocks compared to difficult task-blocks). Here too, the field would benefit from a neurophenomenological approach (Christoff et al., 2011a)—combining moment-to-moment introspective reports collected through experience sampling with concurrent fMRI measures of brain recruitment. Such experience sampling approach has recently been successfully undertaken in several studies (Stawarczyk et al., 2011; Vanhaudenhuyse et al., 2011), that have offered evidence for a role of default network regions in both stimulus-independent and stimulus-oriented thought, but with suggested possible fractionation amongst different default network components.

### 4. Mind wandering

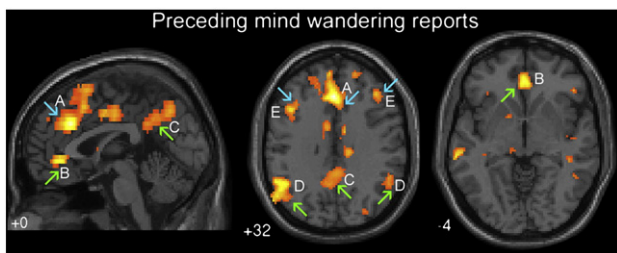
Although there have been relatively few studies of mind wandering (Christoff et al., 2009a; Mason et al., 2007b; McKiernan



et al., 2006), our neuroscientific knowledge of this phenomenon is greater than for either spontaneous thought or stimulus-independent thought due to these studies' use of individual differences analysis and experience sampling approach combined with fMRI measures.

Within the neuroimaging literature, so far mind wandering has most often been defined as thinking that is unrelated to the currently ongoing task or activity (Christoff et al., 2009a; Smallwood and Schooler, 2006). One brain network that has been linked to mind wandering is the default network of brain regions (Raichle et al., 2001), which includes, most prominently, the medial PFC, posterior cingulate/precuneus region, and the temporoparietal junction (TPJ). Studies have demonstrated correlations between reported frequency of task-unrelated thoughts and default network activation during conditions of low cognitive demand (Mason et al., 2007b; McKiernan et al., 2006), as well as stronger default network activation during highly practiced compared to novel tasks in people with higher propensity for mind wandering (Mason et al., 2007b). Furthermore, evidence collected using trial-by-trial experience sampling during fMRI reveals that the three main default network regions are significantly more activated immediately prior to reports of mind wandering compared to immediately prior to reports of being "on-task" (Fig. 1) (Christoff et al., 2009a). Therefore, there is strong evidence to suggest that recruitment of default network regions co-occurs with mind wandering episodes.

However, in addition to default network recruitment, Christoff et al. (2009a) also observed significantly greater executive network recruitment during episodes of mind wandering compared to episodes of on-task attention (Fig. 1). These executive network regions include the DLPFC and the ACC. This joint activation of the default and executive networks during mind wandering may seem highly surprising at first. In general, the executive and default networks are thought to act in opposition to each other so that when the executive network becomes activated, the default network becomes deactivated or actively



**Fig. 1 – Co-activation of executive and default network regions during mind wandering: a combined fMRI/experience sampling study revealed activation in several brain regions prior to reports of mind wandering when participants were behaviorally probed during a sustained attention task. Activations preceding mind wandering reports: executive network regions (downward blue arrows) included dorsal anterior cingulate cortex (dACC) (A) and bilateral dorsolateral PFC (E); default network regions (upward green arrows) included ventral ACC (B), precuneus (C) and left temporoparietal junction (D).**

Figure adapted from Christoff et al. (2009a).

suppressed (Fox et al., 2005; Greicius et al., 2003; Weissman et al., 2006). This mutually exclusive relationship between the two networks may characterize their behavior during experimental conditions such as standard tasks and conditions of rest, but mental phenomena such as mind wandering fall outside the range of such standard experimental conditions. As well, the parallel recruitment of default and executive brain regions during mind wandering is reminiscent of the neural recruitment observed during creative thinking (Kounios et al., 2006, 2008; Subramaniam et al., 2009) where executive regions such as the dorsal ACC and default network regions such as the PCC are activated prior to solving problems with insight. Furthermore, a similar parallel recruitment of executive and default regions has also been observed during naturalistic film viewing (Golland et al., 2007), which is related to immersive simulative mental experience (Mar and Oatley, 2008). Thus, mind wandering may be part of a larger class of mental phenomena that enable executive processes to occur without diminishing the potential contribution of the default network for creative thought (Christoff et al., 2011b; Ellamil et al., 2011; Kounios et al., 2006, 2008; Subramaniam et al., 2009) and mental simulation (Buckner et al., 2008; Schacter et al., 2008; Spreng et al., 2009).

This co-recruitment, however, may occur in the presence of either positive or negative functional connectivity between executive and default network regions. In other words, even though both networks are recruited more so prior to reports of mind wandering relative to reports of being on-task, they may still be negatively correlated through high frequency fluctuations. To disambiguate this, we performed a novel analysis on the same dataset, the results of which are reported next.

## 5. Functional connectivity between large-scale brain networks during undirected thought

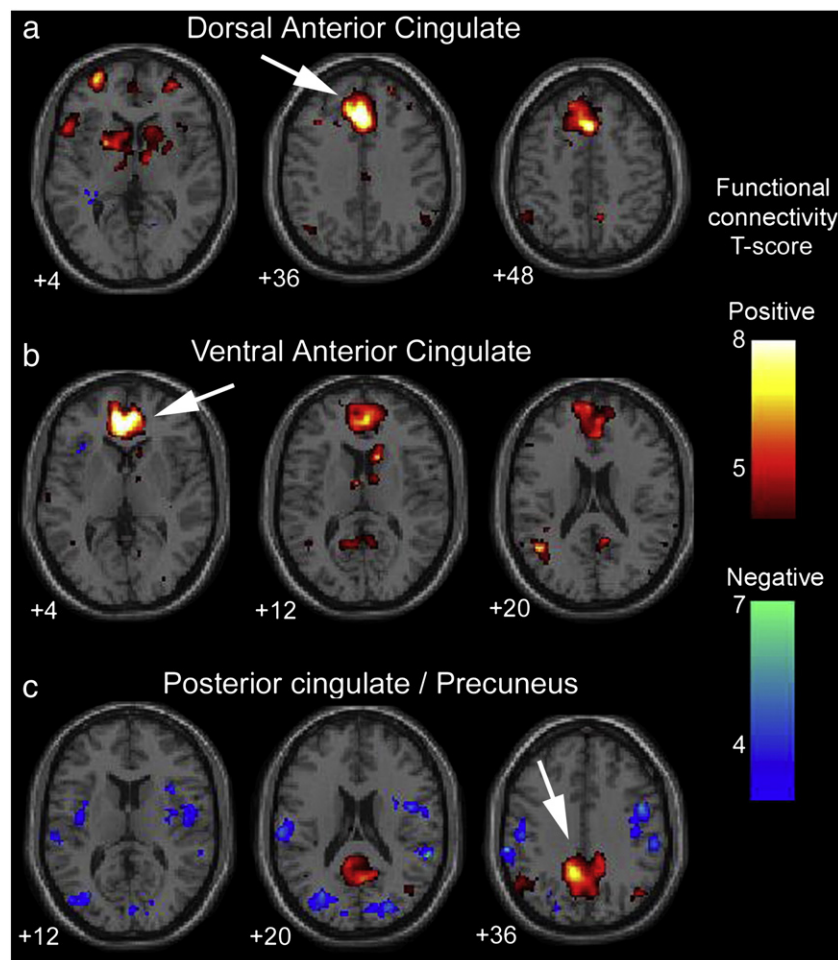
To examine the functional relationship between default and executive network regions during mind wandering, we performed functional connectivity analysis on the dataset from Christoff et al. (2009a). Time series were extracted from three main ROIs activated during mind wandering, as identified in the off-task versus on-task comparison (Fig. 1)—the dACC (part of the executive network), and the vACC and PCC/precuneus (both part of the default network). The ROIs were first defined at the group level, by selecting all voxels that survived a height threshold of  $P < 0.005$  around each of the peak coordinates (dACC,  $x, y, z = 0, 30, 32$ ; vACC,  $x, y, z = 2, 40, -4$ ; and PCC/precuneus,  $x, y, z = -6, -52, 40$ ). Then, subject-specific ROIs were obtained by selecting the largest significant cluster showing off-task vs. on-task activation within the dACC, vACC, and PCC/precuneus group ROIs. For these subject-specific ROIs, we used a reduced height threshold of  $P < 0.05$  uncorrected, because of the restricted search field within the group ROIs. Two subjects had no significant off-task vs. on-task activation within the group dACC ROI, so data were analyzed for 13/15 subjects' dACC. Similarly, one subject had no significant activation within the vACC and four subjects within the PCC/precuneus, so data were analyzed from 14/15 subjects' vACC and 11/15 subjects' PCC/precuneus.

Time series were extracted for the subject-specific ROIs in the dACC, vACC, and PCC/precuneus by averaging the time series of all voxels within the ROI. To minimize the effect of global

drift, the time series was scaled by dividing each time point's value by the mean value of the whole-brain image at that point (Greicius et al., 2003). After this, the scaled time series was filtered using a bandpass Butterworth filter ( $\approx 0.0083/s < f < \approx 0.15/s$ ) to reduce the effect of low-frequency drift and high frequency noise (Lowe et al., 1998). To examine the functional connectivity specific to mind wandering, this time series was then subsampled to select only those values that corresponded to the 10 s intervals prior to "off-task" probes. The resulting time series, representing the average intensity (after scaling and filtering) of all voxels in the ROI during episodes of mind wandering, was then used as a covariate of interest in a whole-brain, linear regression, statistical parametric analysis on all time points corresponding to episodes of mind wandering. Contrast images for this regressor were determined individually for each subject and entered into a second-level random effects

analysis (height threshold  $P < 0.001$  uncorrected) to determine the brain areas that showed significant functional connectivity during mind wandering across subjects.

The results from these functional connectivity analyses are displayed in Fig. 2 and Table 1. The map of dACC connectivity during mind wandering (Fig. 2a) showed significant positive correlations between dACC and a number of other executive network regions, including the rostrolateral prefrontal cortex (BA10) and inferior frontal cortex (BA45/47). In addition, the caudate and a number of cerebellar clusters were also positively correlated. Although weaker and smaller in extent, the dACC also showed positive correlations with two default network regions: the left posterior parietal cortex (BA39/40) and a mid-cingulate cluster that extended into the PCC/precuneus region. No significant regions of negative (or inverse) correlation with the dACC were observed.



**Fig. 2 – Functional connectivity of the dorsal anterior cingulate (dACC), ventral anterior cingulate (vACC), and posterior cingulate (PCC)/precuneus region during mind wandering.** The arrows point toward the approximate location of the seed regions' peaks (dACC,  $x, y, z = 0, 30, 32$ ; vACC,  $x, z, z = 2, 40, -4$ ; and PCC/precuneus,  $x, y, z = -6, -52, 40$ ). (a) dACC showed positive functional correlation with bilateral rostrolateral prefrontal cortex (BA10), bilateral inferior frontal cortex (BA45/48), the PCC (BA 23/31), left posterior parietal cortex (BA39/40), bilateral caudate/putamen and the cerebellum. (b) vACC showed positive functional correlations with the adjacent dACC (BA24/32/9), the superior temporal cortex (BA39), the PCC (BA23/31), the caudate and the thalamus. (c) PCC demonstrated positive functional correlations with the adjacent precuneus (BA23/31/7) and bilateral superior temporal cortex (BA39); it was inversely correlated with the primary motor and somatosensory cortices (BA4/2/3), the extrastriate visual cortex (BA19) and bilateral insula. Height threshold  $P < 0.005$  uncorrected.

**Table 1 – Functional connectivity of executive and default network regions during mind wandering (10-second periods prior to “off-task” reports vs. periods prior to “on-task” reports). All activations were significant at the  $p < 0.001$  level ( $k > 5$ ). Abbreviations: dACC, dorsal anterior cingulate cortex; RLPFC, rostralateral prefrontal cortex; vACC, ventral anterior cingulate cortex; PCC, posterior cingulate cortex; TPJ, temporoparietal junction; L, left; R, right; M, medial; BA, Brodmann area.**

Region	L/R/M	BA	Num of voxels	Z-value	Talairach coordinates		
					x	y	z
<i>Regions positively correlated with dACC</i>							
dACC	M	24/32/9	1479	5.97	–6	28	32
RLPFC	L	10	224	4.56	–30	58	12
RLPFC	R	10	35	3.93	34	50	0
Superior frontal gyrus (lateral surface)	R	10	33	4.28	22	44	24
Inferior frontal gyrus	L	45/47	109	4.9	–50	20	8
Inferior frontal gyrus	R	47	28	3.97	30	24	–8
Mid cingulate gyrus	M	23/31	85	3.86	4	–26	24
Posterior parietal cortex	L	39/40	8	3.32	–54	–60	40
Caudate	R	–	125	4.24	16	4	12
Caudate/putamen	L	–	–	–	–	–	–
Lateral cerebellum	L	–	123	5.62	–6	28	32
Posterior cerebellum	L	–	27	4.68	–34	–82	–32
Lateral cerebellum	R	–	64	5.94	46	–68	–44
Posterior cerebellum	R	–	32	3.68	22	–82	–36
<i>Regions positively correlated with vACC</i>							
vACC	M	24/32	1531	6.17	–2	38	0
dACC	M	24/32/9	–	4.52	6	38	24
PCC	M	23/31	22	3.44	–6	–56	12
TPJ	L	39	50	4.74	–44	–56	20
Caudate	R	–	26	4.27	12	16	12
Thalamus	R	–	17	3.4	0	–2	12
<i>Regions positively correlated with PCC</i>							
PCC/precuneus	M	23/31/7	776	4.25	–6	–52	32
TPJ	L	39	39	4.07	–48	–56	28
TPJ	R	39	73	4.39	44	–70	28
<i>Regions inversely correlated with PCC</i>							
Primary motor and somatosensory cortex	L	4/2/3	45	3.52	–50	–30	48
Primary motor and somatosensory cortex	R	4/2/3	50	3.47	46	–18	48
Extrastriate visual cortex	L	19	48	3.81	–28	–72	24
Extrastriate visual cortex	R	19	26	3.6	28	–80	24
Insula	L	–	65	4.31	–46	4	–8
Insula	R	–	6	3.35	50	12	0

The map of vACC connectivity during mind wandering (Fig. 2b) showed significant positive correlations between vACC and other default network regions such as the PCC (BA23/31) and the temporoparietal junction (TPJ; BA 39). The cluster of vACC functional connectivity extended to include the executive network region of dACC. In addition, the vACC was also positively correlated with the caudate and thalamus. No significant regions of negative correlation with the vACC were observed.

Finally, the map of PCC/precuneus connectivity during mind wandering (Fig. 2c) showed significant positive correlations between this region and another default network region, the TPJ (BA39). A number of brain regions showed significant inverse correlation with the PCC/precuneus, including the primary motor and somatosensory cortex (BA4/2/3), the extrastriate visual cortex (BA19), and the insula.

These results add to the findings of co-recruitment of the executive and default networks reported by Christoff et al.

(2009a), revealing that this co-recruitment occurred in the absence of negative functional connectivity across the two networks and, for some connections across the two networks, the presence of significant positive functional connectivity. The functional connectivity analyses did reveal negative correlations, but not between default and executive network regions. Instead, negative functional connectivity was observed between the default network (PCC/precuneus) and a number of sensory regions including visual and somatosensory cortices.

This negative functional connectivity during mind wandering between the default network and sensory regions is consistent with EEG findings of reduced cortical analysis of the external sensory environment during mind wandering (Smallwood et al., 2008) and attenuated sensory responses (P1 and N1 ERP components) in visual and auditory cortices during mind wandering compared to on-task mental states (Kam et al., 2011). Consistent with this, it has been shown that high levels of mind wandering are associated with

reduction in cortical processing of task-relevant events and distractor stimuli (Barron et al., 2011). Taken together, these findings suggest that mind wandering entails a mental decoupling from the immediate external perceptual environment (Schooler et al., 2011; Smallwood et al., 2011) and could help explain why during episodes of mind wandering people can be oblivious to even salient perceptual events in their external sensory environment.

Furthermore, individual differences in the mind's tendency to take on internal focus of attention away from the external environment may be related to anatomical interrelations between sensory cortices and anterior PFC (default and executive) regions: introspective ability has been shown to be correlated with the anatomical expanse of anterior PFC (Fleming et al., 2010) and there is an inverse relationship between the size of an individual's anterior PFC and the size of their primary sensory (visual and auditory) cortices (Song et al., 2011). Thus, the stability of a person's tendency to engage in undirected thought processes such as mind wandering may at least in part be related to that person's brain anatomy.

Perhaps most importantly, these functional connectivity findings emphasize that the brain's large scale networks interrelate in a flexible, adaptive manner, so that they can work either in concert or in opposition to each other depending on the circumstances (see also Smallwood, 2010). Situations that enable and facilitate undirected thought processes are amongst the least studied and therefore, it is natural to observe functional connectivity patterns (e.g., positive interrelation between default and executive/task-related regions) that investigations of task-oriented cognition have not previously revealed. Finally, even though from a theoretical perspective, mind wandering can be directed towards external perceptual environmental stimuli, the present findings are consistent with the view that it is a predominantly internally oriented mental activity (Singer, 1966), during which attention to the current external perceptual environment tends to decrease.

## 6. Conclusions and future directions

The cognitive neuroscience of thought during the last decade has seen a newly emerged emphasis on undirected thought processes. This emphasis originally came from the ubiquitously observed neural recruitment during rest and was expanded through more recent direct empirical investigation of mind wandering. These investigations have revealed that contrary to most people's intuitive beliefs, the mind may be most active when it is freely wandering outside the confines of particular tasks or goals.

Much remains to be done towards improving the definitions, terminology, and experimental paradigms used to study undirected thought. For example, in the cognitive neuroscience literature so far mind wandering has generally been defined as thought that is "unrelated to the currently ongoing task". But this definition only captures the mind's tendency to wander *away* from something (e.g., the task) and not the mind's tendency to wander *towards* something (e.g., a topic of current concern). In addition, mind wandering can occur even when no task is present, another aspect not

reflected by the current definition. Some researchers have used an even more restrictive definition of mind wandering as thinking that is *both* task-unrelated and stimulus-independent (Stawarczyk et al., 2011). All definitions of mind wandering so far, however, focus on the *contents* of thoughts, rather than on the *process* by which these thoughts arise and become linked in the stream of thought. Part of the focus on thought *content* comes from the fact that it is easier to operationalize and measure (i.e., through introspective reports), while the extent of connectedness between the different segments of thought is much more difficult to measure, especially in the fMRI scanner. In fact, there are no currently available experimental paradigms to measure this connectedness in the fMRI scanner. Thus, even though mind wandering may be better defined in terms of the thought *process*, definitions have gravitated towards the more measurable but potentially less telling thought *contents*. Further empirical and methodological developments will be needed for the phenomena of mind wandering, spontaneous thought and stimulus-independent thought to become better defined and understood.

As well, the unpredictable, uncontrollable nature of undirected thought makes our well developed task-based paradigms largely ineffective for empirical investigations. It is impossible, after all, to instruct participants to have a spontaneous thought. When such thoughts do occur spontaneously, their timing and duration is generally unknown to the experimenter and sometimes even to the participants themselves. Using introspective, first-person subjective reports about one's own mental experience provides a potential promising tool towards overcoming some of these challenges. Furthermore, using participants with greater expertise in introspective observation (e.g., meditators) or providing participants with introspective training could strengthen the validity and utility of these subjective reports (Christoff et al., 2011a).

With such novel methods for empirical investigation, a number of intriguing questions about undirected thought can be investigated. For example, why do memories sometimes evade us during deliberate attempt at recall, but "come to us" later, spontaneously, when we're not deliberately trying to retrieve them? Does recruitment of executive network regions in the service of goal-directed thought lead to suppression of the spontaneous retrieval and generation of thought in medial temporal lobe structures? As well: what is the role of the temporopolar cortex in spontaneous thought? This is one of the least understood and yet frequently activated brain regions when it comes to undirected thought.

The last decade's increase in investigations and interest in undirected thought is encouraging, especially given the empirical challenges stemming from the absence of well developed paradigms for its study. What is more, this decade may well end up marking a paradigm shift within the cognitive neuroscience of thought, from viewing thought from within the prism of task-based, goal-oriented cognition, to broadening our view to include the more nebulous and yet ubiquitous phenomenon of the drifting mind. After all, such mental drift occupies an enormous part of our daily lives. Instead of viewing the mind's drifting quality as a negative, useless, and even harmful aspect of our internal mental lives that we should resist and feel guilty about, such a paradigm shift may help us accept our drifting mind as a normal, even necessary, part of our mental existence—and may even



enable us to try to take advantage of it in some creative, enjoyable way.

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