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The role of spontaneous thought in human cognition

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> "When making a decision of minor importance, I have always found it advantageous to consider all the pros and cons. In vital matters, however, the decision should come from the unconscious, from somewhere within ourselves."
>
> Sigmund Freud

> “When you have to make a decision, the first step should be to get all the information necessary for the decision. Once you have the information, you have to decide, and this is best done with conscious thought for simple decisions, but left to unconscious thought – to 'sleep on it' – when the decision is complex.”
>
> Ap Dijksterhuis

The benefits of deliberate, goal-directed thought processes to decision making have been understood for hundreds of years (Descartes, 1637/1998; Locke, 1690/1979). The idea that deliberately “thinking things through” is the best way to make a decision is at the basis of both classic (Janis & Mann, 1977; Simon, 1955) and contemporary perspectives on decision making (Bettman, Luce, & Payne, 1998; Kahneman, 2003). In contrast, our intuitions and folk wisdom often offer a different perspective, emphasizing the passage of time and the more spontaneous thought processes that occur without conscious control over the direction of the thought process (Bargh, 2001) – a perspective perhaps best captured by the notion that there is a benefit of “keeping something at the back of your mind” and even “sleeping on it”.

The importance of such spontaneous thought processes to decision making has only recently begun to be recognized by experimental scientists (Dijksterhuis, 2004; Dijksterhuis A, 2006a). A growing community of psychologists is beginning to view spontaneous thought as a rich and vibrant cognitive phenomenon with distinct phenomenology and considerable influences on other aspects of cognition (Christoff, Ream, & Gabrieli, 2004; Klinger, 1990; Mason et al., 2007; Singer, 1981; Smallwood & Schooler, 2006). The prevalence of spontaneous thought is striking. Ninety-six percent of American adults report some kind of daydreaming each day (Singer & McCraven, 1961) and approximately 30% of thoughts that people experience in their daily lives can be classified as mind wandering (Kane et al., 2007; Klinger & Cox, 1987). This indicates that spontaneous thought is a ubiquitous phenomenon, occupying as much as a third of our waking life.

Findings from psychology and neuroscience indicate that spontaneous thought shares a number of common attributes with goal-directed thought. For instance, spontaneous thought competes with goal-directed thought processes, just as goal-directed thought processes compete with each other (Teasdale et al., 1995). Our capacity for spontaneous thought increases during highly practiced tasks (Cunningham, Scerbo, & Freeman, 2000; Smallwood et al., 2004; Smallwood, O'Connor, Sudberry, Haskell, & Ballantyne, 2004; Teasdale et al., 1995) and decreases with age (Giambra, 1989, 1995), just as our capacity for goal-directed thought does (Crawford, Bryan, Luszcz, Obonsawin, & Stewart, 2000; Hasher & Zacks, 1988; Schneider & Schifrin, 1977). As well, neuroimaging evidence has demonstrated that the brain regions recruited during spontaneous mentation during rest overlap with those recruited during goal-directed thought (Andreasen et al., 1995; Christoff, Ream, & Gabrieli, 2004; Shulman et al., 1997; Stark & Squire, 2001). These findings have led researchers to argue that spontaneous thought should be viewed as a complex form of cognition worthy of empirical investigation (e.g. Christoff, Ream, & Gabrieli, 2004; Smallwood & Schooler, 2006).

This chapter focuses on the role that spontaneous thought plays in human cognition. We examine its potential place in an overarching framework of thought and compare it to other forms of thought, such as goal-directed and creative, in terms of neural and cognitive mechanisms. We argue that spontaneous mentation shares functions and mechanisms not only with other forms of thought but also with sleep-related cognition. Based on the evidence reviewed in this chapter, we propose that rather than being a futile and wasteful mental activity, spontaneous thought plays a number of important functions in human cognition including, perhaps most importantly, the consolidation and re-consolidation of past and present experiences in relation to our current concerns and emotions.

Different forms of thought and their neural bases

In this chapter, we will talk about three types of thought: goal-directed, spontaneous, and creative. The most studied is *goal-directed* thought, which occurs frequently during reasoning, problem solving, and decision-making paradigms. Indeed, it is this form of thought that psychologists most often have in mind when they refer to thinking. Goal-directed thought is achieved by consciously representing current and desired states, and linking these representations through a series of actions that attempt to transform the current to the desired state (Unterrainer & Owen, 2006).

The other two forms of thought are studied to a much lesser extent. *Spontaneous* thought, including mind wandering, in many ways appears to be the opposite of goal-directed thought. Between these two extreme ends of a possible thought continuum lies yet another form of thinking, *creative* thought, which appears to share commonalities with both goal-directed and spontaneous thought. In this section, we examine these three forms of thought in terms their neural and cognitive basis. We suggest that they differ in terms of the extent to which cognitive control, defocused attention, and long-term memory contribute to each.

Goal-directed thought and cognitive control

The region of the brain most tightly linked to goal-directed thought is the prefrontal cortex (PFC), which spans the anterior expanse of lateral frontal cortical surface (Figure 1). Patient studies throughout the last century have repeatedly demonstrated that lesions to the PFC lead to profound deficits in goal-directed thought (e.g. Duncan, Burgess, & Emslie, 1995; Luria, 1966; Milner, 1964; Shallice, 1982). Neuroimaging findings have yielded further support for this link, arguing for a specific role of the two most anterior lateral prefrontal subregions, the dorsolateral PFC (DLPFC) and the rostrolateral PFC (RLPFC), in planning, reasoning, and problem solving (for reviews, see Christoff & Gabrieli, 2000; Unterrainer & Owen, 2006).

Insert Figure 1 about here

The crucial role PFC plays in goal-directed thought is closely linked to its ability to influence other cortical regions – a function known as cognitive control (Miller & Cohen, 2001). Cognitive control is the process by which PFC selectively biases currently relevant representations in other parts of the brain, thereby helping focus attention on currently relevant stimuli while diminishing attention towards other competing stimuli (Desimone & Duncan, 1995). PFC may play an analogous role during goal-directed thinking, by biasing those thoughts that are relevant to the current goal and allowing them to be selected amongst other competing thoughts, thus keeping mental content “on track” and producing a logically connected train of thought. In this way, cognitive control and its implementation through the recruitment of lateral PFC appear to be some of the characteristic features of goal-directed thinking.

Spontaneous thought, defocused attention and memory

Mind wandering is a much less focused mental state than goal-directed thought. Although the neuroscience of mind wandering is still in its infancy, emerging evidence (Christoff, Gordon, Smith, Smallwood, & Schooler, in preparation; Mason et al., 2007) is beginning to link mind wandering to a set of regions known as the ‘default network’ (Raichle et al., 2001), as well as to regions of the temporal lobe linked to memory processing (Christoff, Ream, & Gabrieli, 2004). Default network regions lie largely along the midline of the brain (Figure 1) and include, most prominently, the medial prefrontal cortex, the anterior and posterior cingulate cortices, the precuneus and the posterior parietal lobule (Raichle et al., 2001; Shulman et al., 1997). This network is typically deactivated during novel, attention-demanding tasks (Raichle et al., 2001), but becomes activated when attentional demands are low, such as during a highly familiar task (Raichle, 1998) or in the absence of a task (Shulman et al., 1997). The accompanying ‘default’ mode of thought is considered to be a state of defocused attention whereby information broadly arising in the external and internal milieu is gathered and evaluated (Raichle et al., 2001). A recent study by Mason et al. (2007) demonstrates that subjects who report a higher propensity to mind wander show greater default network recruitment as cognitive demands decrease. These neuroimaging findings, alongside the long-standing behavioral results demonstrating that mind wandering increases as cognitive demands decrease (Antrobus, 1968; Antrobus, Singer, & Greenberg, 1966), are consistent with the notion that mind wandering is associated with a lowering of cognitive control and a defocusing of attention. Conversely, when focused attention and cognitive control are required, activation in the default network becomes attenuated (Raichle et al., 2001; Shulman et al., 1997).

Besides the default network, spontaneous thought has also been linked to recruitment of structures of the lateral and medial temporal lobe that are associated with memory processing (Figure 1). Thus, periods of 'rest' – an experimental condition during which subjects are typically instructed to lie still in the scanner and 'do nothing' – have been associated with consistent recruitment of the temporal lobe, including medial temporal lobe regions such as the hippocampus and parahippocampus, as well as lateral temporal regions including the temporopolar cortex (Binder et al., 1999; Christoff, Ream, & Gabrieli, 2004; Stark & Squire, 2001). The temporal lobes have long been implicated in long-term memory phenomena such as episodic and semantic memory, and their recruitment during rest has been proposed to reflect ongoing spontaneously occurring memory retrieval and encoding (Andreasen et al., 1995; Binder et al., 1999; Christoff, Ream, & Gabrieli, 2004; Stark & Squire, 2001). Furthermore, recent neuroimaging findings suggest that the off-line processing that occurs during periods of rest, is associated with the kind of memory consolidation processes that occur during sleep (Ellenbogen, Hu, Payne, Titone, & Walker, 2007; Maquet et al., 2000). These findings suggest that long-term memory processes contribute strongly to the phenomenon of spontaneous thought (Christoff, Ream, & Gabrieli, 2004). As we discuss later in this chapter, memory consolidation may be one of the main functions of spontaneous thought.

Creative thought: bringing together the prefrontal, 'default', and memory networks

Similar to spontaneous thought, creative thought processes are also associated with reduced cognitive control. One line of evidence supporting this association comes from studies of electroencephalography (EEG) dynamics during creative thinking. Divergent thinking tasks produces decreased beta range synchrony and increased alpha range synchrony over the frontal cortex (Fink & Neubauer, 2006; Molle et al., 1996; Molle, Marshall, Wolf, Fehm, & Born, 1999; Razoumnikova, 2000; Razumnikova, 2007), providing evidence for a loosened cognitive control and lower prefrontal cortical arousal during creative thought. Another line of evidence comes from findings regarding the pattern of catecholaminergic influences on thought processes. Catecholamines, including noradrenaline and dopamine, are directly linked to cognitive control, prefrontal functioning, and cortical arousal (Chamberlain, Muller, Blackwell, Robbins, & Sahakian, 2006; Cohen & Servan-Schreiber, 1992; Robbins, 1997). Lower levels of these two catecholamines appear to be beneficial for creative thought (for review see Heilman, Nadeau, & Beversdorf, 2003). For example, lowering levels of noradrenaline through the administration of a noradrenaline antagonist improves performance on creative problem solving such as anagram solution (Beversdorf, Hughes, Steinberg, Lewis, & Heilman, 1999; Silver, Hughes, Bornstein, & Beversdorf, 2004). Subjects are also quicker to solve anagrams when lying down than when standing (Lipnicki & Byrne, 2005), an effect linked to the lower noradrenergic system activity when lying down (Svensson, 1987).

Similarly, the administration of L-Dopa, a precursor to both dopamine and noradrenaline, decreases subjects' capacity to access distant semantic relations between concepts (Kischka et al., 1996), thus lowering creative thinking ability. Finally, rapid eye movement (REM) sleep is marked by decreased levels of noradrenaline relative to non-REM (NREM) sleep (Rasmussen, Morilak, & Jacobs, 1986) and a corresponding decrease in cognitive control and increase in hyper-associative imagery (Fosse, Stickgold, & Hobson, 2004). Subjects awoken from REM sleep are better at solving anagrams compared to when awoken from NREM sleep (Walker, Liston, Hobson, & Stickgold, 2002) and show improved access to distant semantic relations between concepts (Stickgold, Scott, Rittenhouse, & Hobson, 1999). Thus, lowering cognitive control and arousal, as well as shifting attention from a focused state to a wider, defocused attentional state, enables a transition from a relatively goal-directed thinking mode to a more associative, creative mode. This state of defocused attention may be one of the key factors facilitating creative thought (Gabora, 2002, 2003; Heilman, Nadeau, & Beversdorf, 2003; Howard-Jones & Murray, 2003; Mendelsohn & Mendelsohn, 1976).

A further parallel between spontaneous and creative thought is the observed recruitment of regions of the default and memory networks for both types of thought processes. For example, the occurrence of insight during remote associate problems is linked to activation in temporal lobe regions, such as the anterior superior temporal gyrus (aSTG) and the parahippocampus, as well as the medial prefrontal cortex and the posterior cingulate (Jung-Beeman et al., 2004). Furthermore, in a study designed to investigate the mental set prior to solving insight problems, Kuonios and colleagues (2006) found that default network regions (ACC and PCC) are more active prior to the presentation of remote associates problems that were subsequently solved with insight, compared to those solved without insight. Default network regions (anterior medial frontal cortex and ACC) are also activated when subjects generate creative compared to uncreative stories, and when they generate a story from a list of unrelated words compared to a list of related words (Howard-Jones, Blakemore, Samuel, Summers, & Claxton, 2005). This facilitation of semantic divergence and insight solutions may be linked to the wider and looser attentional focus associated with activation of default network regions, while the recruitment of temporal lobe regions may be important for the generation of associations and their semantic integration (Achim, Bertrand, Montoya, Malla, & Lepage, 2007; Lepage, Habib, Cormier, Houle, & McIntosh, 2000).

In addition to the memory and default networks, some types of creative thought – particularly those that require more control and focused attention – require recruitment of lateral PFC. For example, a typical divergent thinking task is to generate as many different uses for a brick as possible (de Bono, 1970). This task requires the evaluation of each generated use for its appropriateness and its novelty with respect to the other uses already generated (Feist, 1998). Such evaluative functions are tightly linked to lateral PFC functions, and PFC recruitment has been observed when creative individuals engage in this divergent thinking task (Carlsson, Wendt, & Risberg, 2000). In addition, the PFC is also recruited for creative thinking tasks that require shifting from traditional to more novel strategies (e.g. Camfield, 2005; Heilman, Nadeau, & Beversdorf, 2003), a finding consistent with the long established role of lateral PFC in task-switching (Buchsbaum, Greer, Chang, & Berman, 2005).

Other forms of creative thought may be associated with less prefrontal recruitment. One example is the state of ‘flow experience’ characterized by the performance of a task seemingly without effort but to the best of one’s ability (Csikszentmihalyi, 1990). Such flow states are considered to be accompanied by a diminished prefrontal recruitment compared to other forms of creative thought (Dietrich, 2004). It has been proposed that creative thought includes different components: first, a generative stage relying on the generation of novelty and access to remote semantic associations, which appears to be linked to ‘default’ network and memory regions; and second, the evaluative aspects, which may be most strongly linked to lateral prefrontal recruitment.

Thus, creative thought appears to be in a unique position of involving the contribution of cognitive control (lateral PFC), defocused attention (default network), and memory (temporal lobes). In contrast, goal-directed thinking appears to require a proportionately higher contribution from cognitive control (lateral PFC) and is associated with some of the lowest contributions from the default network, presumably because the state of heightened attention it requires displaces the state of defocused attention associated with default network recruitment. Finally, mind wandering is associated with a relatively limited contribution from lateral PFC, but relatively high default and memory network contributions (see Figure 2). Keeping in mind these relationships between mind wandering and other forms of thought, we next turn to the question of the possible functions of spontaneous thought.

Insert Figure 2 about here

Spontaneous thought, sleep and memory consolidation

Spontaneous thought may appear to occupy one extreme end of a thought continuum in terms of cognitive control. However, if we view it as part of a broader continuum of wake-sleep mental states (Fosse, Stickgold, & Hobson, 2001), it would represent only a mid-point between the highly focused attention of active wakefulness, on the one hand, and the extreme lowering of cognitive control during sleep, on the other hand. Evidence for this extreme lowering of cognitive control during sleep comes from findings of consistent down-regulation of lateral PFC activation during sleep compared to resting wakefulness (Braun et al., 1997; Maquet et al., 1996; Nofzinger, Mintun, Wiseman, Kupfer, & Moore, 1997), as well as aminergic demodulation and cholinergic activation (Mamelak & Hobson, 1989; Sutton, Mamelak, & Hobson, 1992). In addition, cognitive studies show that the frequency of thought decreases as one moves from a state of quiet wakefulness to sleep onset, and continues to decrease during NREM sleep until it reaches its nadir during REM sleep (Fosse, Stickgold, & Hobson, 2001). The frequency of hallucinations, on the other hand, follows the opposite trend, with lowest occurrence during quiet wakeful state and peak occurrence during REM sleep (Fosse, Stickgold, & Hobson, 2001). While REM and NREM differ along various dimensions, this difference appears to be a matter of degree; the same phenomena occur during both types of sleep states, but tend to be observed more frequently during REM (Fosse, Stickgold, & Hobson, 2001; Ji & Wilson, 2007; Sutherland & McNaughton, 2000; Wilson & McNaughton, 1994).

The proximity of resting wakeful states to sleep states on a wake-sleep continuum suggests that spontaneous thought, which is most likely to occur during resting states, may bear important similarity in its functions and mechanisms not only to waking thought processes, but also to sleep-related mentation. Indeed, recent theoretical proposals and experimental evidence is beginning to link the phenomenon of off-line processing during sleep to the off-line mental processing that occurs during wakefulness.

Off-line processing during sleep

The kind of off-line processing that occurs during sleep is known to benefit subsequent thinking, decision making, and memory in crucial ways. Not only is sleep deprivation detrimental to cognitive functioning in general, but there are clear improvements in memory and problem-solving ability after a period of sleep compared to after a period of wakefulness (Ellenbogen, Hu, Payne, Titone, & Walker, 2007; Hu, Stylos-Allan, & Walker, 2006; Wagner, Gais, Haider, Verleger, & Born, 2004).

The memory improvement associated with sleep has been linked to what appears to be a replay of recent experiences in the cortex and hippocampus. Single-cell recordings in the rat show that cells that fire together during a waking experience tend to also fire together during subsequent REM sleep (Wilson & McNaughton, 1994) and NREM sleep (Ji & Wilson, 2007; Sutherland & McNaughton, 2000). This replay is temporally structured and can reflect from tens of seconds to minutes of behavioral experience reproduced at an equivalent timescale (Louie & Wilson, 2001), suggesting episodic memory trace reactivation during sleep.

Dreaming in humans may be a manifestation of a similar replay of experiences at the neuronal level. Findings from neuroimaging studies in humans show that brain regions that are activated during learning experiences are re-activated during subsequent REM (Maquet et al., 2000) and NREM sleep (Peigneux et al., 2004a). Moreover, the amount of activation in hippocampus and parahippocampus during NREM sleep is positively correlated with performance improvement on the following day (Peigneux et al., 2004a). Consistent with these findings, dreaming about newly-learned material enhances subsequent recall of that material (Nielsen & Stenstrom, 2005) and pre-sleep stories are better recalled in the morning if subjects dreamt frequently about constituents of the stories during the night (Fiss, Kremer, & Litchman, 1977). Thus, the off-line replay of episodic experiences during sleep appears to be associated with subsequent improvements in memory and performance.

The literal replay of episodic memories, however, occurs very rarely during sleep (about 1-2% of dream reports, Fosse, Fosse, Hobson, & Stickgold, 2003). Instead, the reproduction of isolated fragments of episodic memories is much more common (about 28-38%, Cavallero, Foulkes, Hollifield, & Terry, 1990). Moreover, memory elements that are reproduced during sleep derive their sources not only from relatively recent experiences arising during the day or week before the dream (Nielsen, Kuiken, Alain, Stenstrom, & Powell, 2004) but also from fairly old memories such as those arising from between ages 10 and 19 (Grenier et al., 2005). It seems that far from simply being the passive reactivation of recent memories, off-line processing during sleep is a much more active, complex activity.

Recent theories about the functions of sleep are beginning to view it as an active process of memory consolidation and re-consolidation (Maquet, 2001; Stickgold, Hobson, Fosse, & Fosse, 2001), with memories re-activated in order to alter their strengths, structures, and associations (Stickgold, Malia, Maguire, Roddenberry, & O'Connor, 2000) and link them adaptively to current motivational concerns (Paller & Voss, 2004). The physiological properties of REM sleep (tonic aminergic demodulation and phasic cholinergic activation) are thought to lead to hyperassociative mentation, marked by an increase in unexpected associative sequences (Mamelak & Hobson, 1989; Sutton, Mamelak, & Hobson, 1992) and a preferential access to weak, unusual associations between concepts (Stickgold, Scott, Rittenhouse, & Hobson, 1999). For instance, when objects in dreams are suddenly and unexpectedly transformed into other objects, they are normally related to each other by unpredictable and weak associations (Rittenhouse, Stickgold, & Hobson, 1994). In this way, the off-line processing during sleep appears to allow for unpredictable but potentially valuable associations to be tested and strengthened, if appropriate (Stickgold, Malia, Maguire, Roddenberry, & O'Connor, 2000) – by strengthening connections among dispersed cortico-cortical and hippocampo-cortical connections (Paller & Voss, 2004).

Importantly, memories appear to be consolidated adaptively, in relation to current problems, goals, and experiences (Paller & Voss, 2004). The contents of dreams are often structured around the individual’s dominant, pre-sleep concerns (Hartmann, 1998) and emotions appear to play a key role during this consolidation process (Nielsen & Stenstrom, 2005). The amygdala, which controls the encoding and retrieval of emotional memories and maintains direct reciprocal connections with the hippocampus, is activated more so during REM sleep than during wakefulness (Hobson, Hobson, Pace-Schott, Stickgold, & Kahn, 1998). Together with the hippocampus, it plays a crucial role in the process of transforming emotionally rich episodic memories into semantic memories of lower emotional charge – a crucial aspect of memory consolidation.

The process of 'dismantling' episodic memories of their contextual and emotional associations and consolidating them into semantic memory is considered to be tightly linked to medial temporal lobe functioning. However, while the hippocampus serves to provide access to complete episodic memories during wakefulness (Moscovitch, Nadel, Winocur, Gilboa, & Rosenbaum, 2006), its function during sleep appears to be different (Nielsen & Stenstrom, 2005). The replay of episodic memories that occurs during sleep is not dependent on the hippocampus and, if anything, occurs more frequently when the hippocampus is damaged. The dreams of patients with hippocampal damage frequently replay complete episodic memories of actual events in a stereotyped, repetitious way, and without symbolic elaborations (Torda, 1969). Similarly, patients with post-traumatic stress disorder (PTSD), who suffer diminished hippocampal capacity, experience the frequent replay of nightmares that are highly episodic in nature (Mellman, 1997), suggesting a dysfunction of cortical memory consolidation during sleep.

Overall, the functions of off-line processing during sleep appear to be geared towards the incorporation of new episodic memories into semantic memory (consolidation) and the re-activation of old memories and associations in order to adaptively change their strength and connections (re-consolidation). As cholinergic transmission rises and aminergic transmission decreases, a progressive disinhibition of numerous cortical and subcortical systems occurs, including internal pulse-generation systems such as the anterolateral pons, which leads to progressive excitement of the multimodal sensory areas (Fosse, Stickgold, & Hobson, 2001) that may lead to the spontaneous reactivation of memories. At the same time, medial temporal lobe structures, including the hippocampus, contribute to the adaptive consolidation of these memories and to the altering of their association strengths. Indeed, sleep is considered to be an obvious time for such a replay and cortical modification to occur, because there is no competition from external sensory inputs that ordinarily have strong influence upon multimodal sensory cortices during active wakefulness (Stickgold, 1998). However, conditions during restful wakefulness, when an individual is not engaged in an active task involving the processing of external sensory inputs, resemble closely those during sleep. Indeed, the functions of sleep are beginning to provide clues regarding the possible functions of off-line mental processing during wakefulness.

Off-line processing during wakefulness

Recently emerging evidence has suggested that off-line processing during wakefulness resembles in its functions and effects the off-line processing that occurs during sleep. For instance, a neural replay of recent experiences during periods of quiet wakefulness has been observed in the rat, reminiscent of the replay observed during sleep (Foster & Wilson, 2006; Sutherland & McNaughton, 2000). Similarly, recent neuroimaging studies in humans demonstrate that neural activity related to post-training learning and memory consolidation occurs during the period of wakefulness following training. Thus, learning-dependent changes have been observed in spontaneous brain activity while subjects perform an unrelated task after learning either a spatial or procedural memory task (Peigneux, Schmitz, & Willems, 2007). Similar learning-dependent post-training neural activity for the same tasks is known to occur during both NREM (Peigneux et al., 2004b) and REM sleep (Maquet et al., 2000).

Recent behavioral findings in humans complement these neural results by demonstrating that there are memory improvements that follow periods of wakefulness, resembling those that occur after equivalent periods of sleep (Ellenbogen, Hu, Payne, Titone, & Walker, 2007). Thus, memory consolidation appears to occur during both wakefulness and sleep, with off-line processing beginning during the wakefulness following given experience, and continuing during subsequent sleep (Peigneux et al., 2006). Spontaneously arising cognitions during wakefulness, that are often experienced in the form of mind wandering, may then represent, at least in part, the products of the memory consolidation process.

Mind wandering as a manifestation of off-line processing during wakefulness

In the same way that night-time dreams are considered to be linked to the reactivation of experiences in the process of their memory consolidation, mind wandering may be the result of a similar reactivation of experiences and their combination in the process of off-line memory consolidation and re-consolidation. The replay of experiences during wakefulness may be facilitated by relatively low levels of external stimulation (e.g., quiet restful environment) or by the turning of attention away from external stimuli (i.e., "tuning out") – both of which are known to be associated with higher incidence of mind wandering (e.g., Singer, 1981; Smallwood & Schooler, 2006). During these states, the involvement of sensory cortices with external stimuli would be lower, which would facilitate the cortico-hippocampal interplay that is considered to be crucial for the process of memory consolidation (McClelland, McNaughton, & O'Reilly, 1995).

Thus, mind wandering may be the subjective experience resulting from ongoing off-line processing, including the reactivation and recombination of recent experiences. When it occurs during a task, mind wandering may be a manifestation of off-line processing that occurs in parallel with task-related thought. It could lead to the experience of a frustrating distraction or a sudden insight. In the absence of a task or under conditions of low attentional demand, off-line processing may be richer and manifest itself in the form of day dreaming. Regardless of the situation in which it occurs, however, off-line processing during wakefulness appears to be just as necessary for successful semantic memory formation as off-line processing during asleep. The effect of this off-line processing on subsequent performance and memory may explain why despite its reputation for uselessness, mind wandering is in fact associated with a number of benefits for cognition and memory.

Cognitive benefits of spontaneous thought

A growing body of research demonstrates that spontaneous mentation can be highly beneficial in a wide range of cognitive domains, from memory and thought, to emotion, motivation, and decision making. In this section, we review findings which suggest that far from being an undesirable and wasteful distraction from task-related activity, spontaneous thought appears to be a highly beneficial, essential part of human cognition.

Memory and thought

One particularly striking example of the benefit of off-line processing for memory comes from a study of relational memory by Ellenbogen and colleagues (2007) who found greater inferential ability on a transitive inference task following an extended period of off-line processing (a 12 hour delay during which subjects remained awake) as compared to a shorter time period (a 20 minute delay). During a transitive inference task, subjects learn premise pairs then later apply the interrelationships between these pairs to infer the relationship between items not previously presented together. For example, after learning the premise pairs A>B and B>C, when presented with the item A?C, one would infer that A>C. The 12-hour group showed improved relational memory compared to the 20 minute group. The memory improvement on items with one degree of separation was very similar to the improvement observed after 12-hour delay that included sleep (although after sleep, an additional improvement on items with two degree of separation was observed). Thus, off-line processing during wakefulness appears especially beneficial for the consolidation of associations and relational memory.

Spontaneously occurring cognition also benefits goal-directed and creative thought by enriching the outcome of the thinking process and broadening its scope. Although it has been notoriously difficult to study, the thought phenomenon of insight is considered to occur spontaneously following a period of off-line processing (e.g., Dorfman, Shames, & Kihlstrom, 1996; Gabora, in press; Schooler & Melcher, 1995; Smith, 1995; Wallas, 1926). Spontaneous cognition has also been closely linked to creative thought. Many creative artists and scientists have linked important insights to their daydreams (Klinger, 1990) and empirical findings show that the frequency of reported daydreaming is correlated with a subject's creativity (Singer & Schonbar, 1961). Experimental findings also show that when a creative task is preceded by a period of distraction, the generated ideas are less obvious and more creative compared to those generated after an equivalent period of deliberate thought (Dijksterhuis A, 2006b). This phenomenon has been ascribed to the unfocused, spontaneous thought processes occurring during a distracting task (Dijksterhuis A, 2006c). The benefits of spontaneous cognition for creative thought is perhaps best recognized by modern practitioners in the creative fields, who regard spontaneously occurring thought as one of the two key components of the creative process – a crucial part of the interplay between critical and spontaneous cognition known as “flip-flop” thinking (Charles Dobson, personal communication).

Emotion and motivation

Spontaneous thought has also been shown to have a beneficial effect on emotional processing. For example, in one study by Paton et al. (reported by Singer, 1981), subjects were insulted by an experimenter while performing a task. Following the insult, one group of subjects were shown either neutral or aggressive images and instructed to use them to construct fantasies while another was not given the opportunity to engage in fantasy. Subsequently, the insulted group which did not have an opportunity to mind wander reported higher levels of anger than both mind-wandering groups, suggesting that mind wandering can provide a form of effective emotional regulation and the opportunity to formulate an alternate perspective in assessing one's emotions.

The content of spontaneously occurring mentation, such as mind wandering and daydreaming, is known to be closely related to current concerns and motivations (Singer, 1981). An interesting connection between off-line processing and motivation has been suggested by findings from single-cell recordings in the rat that have revealed a replay of experiences during restful wakefulness (Foster & Wilson, 2006). This replay has a unique, reverse form. For example, if the rat visited locations A, B, and then C, while running on a track in search of a reward, this sequence would be replayed as C, B, and then A while the rat is resting on the track, having reached the reward. Foster and Wilson proposed that this reverse replay serves the process of assigning motivational value to experiences through reward-related dopamine release: those experiences that are temporally closer to the reward, and hence more predictive of a reward, are replayed first and assigned a higher motivational value through dopamine release; the further away from the reward an experience is, the later it is replayed, thus achieving the assignment of a decreasing gradient of motivational value to experiences depending on the extent to which they predict a reward. This assigning of value provides the advantage of increasing the availability of information regarding a reward, thereby potentially allowing it to guide choice at locations distant from the goal. Thus, the replay of events during periods of rest seems to be of significance for motivational learning, in addition to its role in memory consolidation.

Decision making

Spontaneous, unconscious thought also appears to benefit decision making, especially when it comes to complex decisions. This phenomenon is clearly illustrated in the work of Ap Dijksterhuis and colleagues (e.g. Dijksterhuis, 2004; Dijksterhuis A, 2006a). In a series of studies, subjects received information about various alternatives (e.g., apartments, roommates) with the goal to decide what alternative is the most attractive (Dijksterhuis, 2004). Subjects chose either immediately, or after a period of deliberately thinking about the various alternatives, or after performing a distracting task (n-back or anagram solving) during which their attention was turned away from the alternatives. During this distraction period, participants were assumed to engage in unconscious, spontaneously occurring thought. Out of the presented alternatives, one alternative was classified by the experimenter as the best choice due to it being characterized by more positive and fewer negative attributes as compared to the other alternatives. Subjects who performed a distracting task made a better decision, as indexed by making a stronger distinction between the most attractive alternative and the least attractive alternative, than those who were asked to consciously deliberate prior to making their decision. Supporting the assumption that participants were engaging in unconscious, spontaneously occurring thought, additional evidence indicated that the mental representations of the various alternatives changed during the distraction period, having become clearer and better organized, eventually having led to better decisions.

This benefit of spontaneous thought may be particularly relevant to complex decisions that require a large amount of information to be considered. This was illustrated in a study in which subjects were asked to select which one of four cars they would buy, given a list of each car’s attributes (Dijksterhuis A, 2006a). Decisions were classified as either simple (4 attributes) or complex (12 attributes) based on the number of attributes ascribed to each car. The attributes were either positive or negative. The cars were characterized by differing percentages of positive attributes. Subjects were either asked to think about the cars for 4 minutes prior to making their choice or they were given a distraction task (anagram solving) for 4 minutes and were told that following this task they would be asked to select the best car. The group of subjects that engaged in deliberate thought regarding their decision made a better choice in the simple decision conditions. For the complex decision, however, the group that performed a distracting task made a better decision compared to the deliberate thinking group. This effect could be due to the fact that deliberate, conscious thought has a relatively low capacity (Miller, 1956), leading choosers to take into account only a subset of the relevant information for a given decision (Dijksterhuis, 2004; Wilson & Schooler, 1991). Spontaneously occurring unconscious thought, on the other hand, has a much broader focus, allowing for large amounts of information to be integrated into an evaluative summary judgment (Dijksterhuis, 2004). As well, as mentioned previously, evidence suggests that reorganization of representations occurs during unconscious thought leading to clustering and polarization of information, thus, allowing for better decision making (Dijksterhuis, 2004; Dijksterhuis A, 2006a)

In summary, the findings indicate that far from being wasteful and undesirable, spontaneous thought can be shown to produce strong benefits throughout human cognition and everyday life. While the negative aspects of spontaneous thought are typically emphasized, it is important to keep in mind the existence of these benefits. It is up to future research to develop a greater understanding of the mechanisms by which spontaneous thought occurs and the circumstances that bring about both its beneficial and detrimental interactions with cognitive processes.

Conclusions

We often rebel against our own propensity to engage in spontaneous thoughts and try to banish them from our minds, treating them as a harmful distraction. Whether we like it or not, however, we spend a third of our waking lives engaged in thoughts unrelated to the present task (Kane et al., 2007; Klinger & Cox, 1987). We now know that the third of our lives we spend on sleep is by no means wasteful but is instead, necessary for us to be able to function during the remaining two thirds of our lives. It may well turn out that spending a portion of our waking lives letting our mind wander is just as important for our successful functioning during the remaining waking time when we may be engaged in more deliberate, focused thought.

The kind of spontaneous thought processes that occur during periods of distraction or rest appear to facilitate memory consolidation – or the integration of isolated episodic experiences into a coherent, meaningful autobiographical structure that gives us a sense of self. Similarly to sleep, the function of spontaneous thought may be to help us make sense of our experiences by building a coherent and meaningful structure out of the isolated, and at first unrelated events, that constitute our everyday lives. In contrast to sleep, however, wakefulness may allow this integration to occur at a more conscious level – by allowing spontaneous thought to interact with deliberate, goal-directed thought.

When we let our mind wander, we shift our mode of thinking to a more spontaneous, less controlled kind of thinking, which can help us reach more creative, less predictable conclusions. This could broaden the amount of information and the number of factors we could take into account while thinking. It seems that in most cases when it produces a cognitive benefit, spontaneous thought either proceeds or follows a period of more goal-directed, deliberate thought. This temporal alternation between the two different modes of thought may be what leads to some of the most beneficial outcomes, such as new insights, deeper levels of understanding, and novel, creative ideas. The nature and mechanisms of this alternation, as well as the existence of an optimal proportion of time spent in each thinking mode, remain to be examined in future research.

Perhaps one of the biggest benefits brought about by spontaneous thought appears to be in the area of complex decision making. Spontaneous thought facilitates the process of making sense of our experiences, the drawing of connections between memories and concepts, the broadening of attentional focus to include larger amount of information into consideration, and the process of assigning motivation value to experiences – all factors that are essential in making a good decision in a complex situation.

The American playwright Lillian Hellman once said, "Decisions, particularly important ones, have always made me sleepy, perhaps because I know that I will have to make them by instinct, and thinking things out is only what other people tell me I should do". Her intuition regarding the importance of instinctual, spontaneous thought in making complex decision has been borne out in multiple psychological findings since. The process of deliberately thinking things out may be a part of the decision process, but it is the more spontaneous, defocused thinking mode – which Hellman correctly intuited as vaguely reminiscent of sleep – that may be necessary for important decision to be successfully made. Although things are beginning to change, to this day, the majority of what we know about spontaneous thought comes from our intuitions and subjective introspections. One thing, however, is fairly clear; further progress in our understanding of human thought and decision making would be impossible without taking into account spontaneous thought, which presents some of the biggest challenges to experimental investigation and yet holds some of the biggest promises for the advance of our understanding.

Figure captions

Figure 1. Approximate anatomical localization of the lateral prefrontal cortex, the default network, and temporal lobe memory regions. Abbreviations: mPFC, medial prefrontal cortex; mSFG, medial superior frontal gyrus; PCC, posterior cingulate cortex; IPL, inferior parietal lobe.

Figure 2. Proposed relative contribution of the lateral PFC, temporal lobe memory regions and the default network to goal-directed, creative, and spontaneous thought.

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