The Journal of Mind and Behavior
Summer 2018, Volume 39, Number 3
Pages 155–180
ISSN 0271–0137

How Sustainable are Different Levels of Consciousness?

Erik J. Wiersma

Alba Biologics

The human brain processes a wide variety of inputs and does so either consciously or subconsciously. According to the global workspace theory, conscious processing involves broadcasting of information to several regions of the brain and subconscious processing involves more localized information processing. This paper expands on some of the aspects of the theory: how the properties of incoming information result in the input being processed subconsciously or consciously; why processing can either be sustained or short-lived; how the global workspace theory may apply both to real-time sensory input as well as to internally retained information. This paper proposes that: familiar input which evokes weak emotions becomes processed subconsciously and such processing can be continuous and sustained; input that elicits stronger emotions is subjected to highly sustainable conscious processing; input can also undergo meta-conscious processing. Such processing is not very sustainable but can exert control over other cognitive processes. This paper also discusses possible benefits of regulating cognitive processes this way.

Keywords: consciousness, global workspace theory, emotion

An important concept in behavioral sciences and in philosophy is that we are not conscious of (i.e., we are not able to report about) all of our mental processes, and that subconscious processing constitutes a large part of our mental activities and directs many of our actions (Bargh and Morsella, 2008; Dehaene, 2014, pp. 47–88). In order to gain a broad and comprehensive understanding of mind and behavior it is useful to consider both subconscious and conscious processing. In his global workspace theory Baars (1997) proposes how subconscious and conscious processes are related: he metaphorically likens the mind with a theatre that is mostly dark, or subconscious, albeit with a small "bright spot," the conscious part. This bright spot exchanges "both convergent input and divergent output" with the dark parts of the theatre. This wide-ranging exchange of information, or connectivity within the "global workspace," is viewed as being

---

This work was not supported by funding. The author would like to thank Vince Taguchi, Alain Morin, Stan Franklin, Donald Stewart and the anonymous journal reviewers for their valuable comments on this paper. Correspondence concerning this article should be addressed to Erik J. Wiersma, Alba Biologics, 144 Bowood Ave., Toronto M4N 1Y5, Ontario, Canada. Email: erikwiersma@rogers.com

critical to consciousness (Baars, 2005). The bright spot of consciousness is not fixed — different regions of the brain can ignite broadcasting, so called "any-to-many signaling" (Baars, Franklin, and Ramsoy, 2013).

The global workspace theory has received some experimental support (reviewed by Baars, Franklin, and Ramsoy, 2013). During the onset of conscious processing there is a shift from isolated local processing towards shared, global processing. Broadcasting is facilitated by the thalamus supporting a cortical "up state," enabling different cortical regions to communicate with one another in a synchronized fashion (Rigas and Castro–Alamancos, 2007; Steriade, McCormick, and Sejnowski, 1993). Cortical broadcasting leads to extensive cognitive resources being spent on one (out of many) streams of information so that the information is processed accurately and effectively. Ongoing competition for mental resources determines which stream of information will be broadcasted. When information is processed consciously it is often perceived as being unitary and internally consistent — this is likely a result of utilizing substantial resources on focussed processing. Over time the brain's focus will shift to different streams of input (Hasenkamp, Wilson–Mendenhall, Duncan, and Barsalou, 2012; James, 1890, p. 243; Logothetis, Leopold, and Sheinberg, 1996; Vanhaudenhuyse et al., 2010). This ability, to re-direct the brain's cognitive resources, is of course useful when responding to a changing environment.

Different Levels of Consciousness

Experiments utilizing functional magnetic resonance imaging (fMRI) indicate that consciousness coincides with integrated activation of different brain regions (Fahrenfort et al., 2012; Godwin, Barry, and Marois, 2015). Also, it has been possible to dissect the onset of conscious processing (Dehaene, 2014, pp. 121–142) both in terms of stimuli thresholds that need to be exceeded, as well as tracking the time course of how different brain regions become successively involved during the onset of consciousness. Studies provide support for three levels of cognitive processing (Dehaene, 2014, pp. 190–193; Dehaene, Changeux, Naccache, Sackur, and Sergent, 2006). The simplest level, subliminal processing, is due to stimuli having weak bottom–up strength. Such stimuli do not result in wide broadcasting or the ability to report on the stimuli. The next level, pre-conscious processing, is caused by strong stimulus in the absence of strong top–down attention. It has the potential of becoming reportable, albeit after a temporal delay. These two levels are subconscious.[1] The third level, conscious processing, is caused by strong stimulus strength and strong top–down attention, and it is reportable. Zylberberg, Slezak, Roelfsema, Dehaene, and Sigman (2010), and Zylberberg, Dehaene, Roelfsema, and Sigman (2011) describe reverse engineering where these levels of

[1] The remainder of this paper will not use the term "subconscious." Instead, I will use either "subliminal" or "preconscious," the two sub-levels that constitute subconsciousness.

brain processes were modeled by a computer software. The model is an *in silico* representation of large numbers of interacting neurons, and mimics the neural spike patterns that occur in response to sensory inputs. This software was able to accurately replicate some aspects of short-term processing of simple visual stimuli. This model, described in three publications (Dehaene et al. 2006; Zylberberg et al. 2010, 2011), will be referred to as "the Router model."

Importance of Sustained Cognitive Processing

LIDA (reviewed by Franklin et al., 2016) is another computer model based on the global workspace theory. It is a flexible framework aimed at replicating general human cognitive capabilities such learning, adaptation, and autonomy. This framework is customizable and has been explored for practical applications such as providing human resources services and medical diagnoses. Similar to the Router model, LIDA has three levels of cognitive processing, and incoming sensory input is routed to any of these levels through their degree of salience (Franklin and Baars, 2010). High level processing, which is accurate but slow, involves a greater number of cycles of repeat processing than do simpler levels of processing (Faghihi, Estey, McCall, and Franklin, 2015). This feature, to undergo consecutive and iterative rounds of processing, contrasts with the Router model's short-term start-to-finish processing. Repeated, sustained processing is an important step towards replicating human-like cognition.[2] Humans often perform consecutive rounds of cognitive processing to solve problems (Dehaene and Sigman, 2012), each round lasting hundreds of milliseconds. Also, some aspects of conscious experiences require integration of input received at different points in time, i.e., carry-over of information from one round of cognitive processing to the next. One aspect is that a sense of continuity, such as continuous motion, is obtained by integrating sensory information from different time points (Geldard and Sherrick, 1972; Kolers and von Grünau, 1975). Another aspect is that temporal integration enables patterns to be recognized; it has been claimed that the ability to recognize patterns in a long auditory sequence is a marker of conscious processing (Bekinschtein et al., 2009). An additional aspect is that temporal integration is important for the richness of a conscious experience. Our visual experience of the environment is often richer than the information we perceive at any given instance and this is because of temporal integration (Melchers and Morrone, 2007). Taken together, integrating information from sustained, repeated cycles of cognitive processing appears to be important for several attributes of human consciousness.

---

[2] "Sustained" is defined as a stream of information undergoing consecutive rounds of cognitive processing. "Sustainable" is defined as information having a high probability of undergoing consecutive rounds of cognitive processing.

Sensory-Coupled Cognition

The brain can rapidly and accurately process a diverse and vast amount of information. This involves both real-time processing of input sensory organs, which is briefly summarized below, as well as processing information that is not directly coupled to sensory input, discussed in the next section. Efficient processing of sensory input is made possible by several operating principles, outlined in the next three sections.

Parallel Processing

The brain deploys a high degree of parallel and distributed processing during initial steps of cognition (Cisek and Kalaska, 2010; Feldman and Ballard, 1982; Nassi and Callaway, 2009). Such a principle, which operates at different anatomical scales of the brain, allows for efficient processing. At the smaller scale, parallel processing is carried out by a large number of neural processors that are arranged in series and in layers (Hinton, 2007; Poggio, 2016). These serial layers form local networks with signalling among adjacent layers.

Parallel processing also operates at the brain's larger anatomical scale. Distinct brain regions carry out primary processing for different sensory streams, e.g., there are separate centres for visual, auditory, and olfactory inputs. Such brain regions, as well as more domain-general regions, are connected through network hubs (Bola and Sabel, 2015; Moon, Lee, Blain–Moraes, and Mashour, 2015; van den Heuvel and Sporns, 2013). Structural analysis, which maps the anatomy of neural wiring, reveals different classes of hubs, with some hubs providing local, short-range connections. Other, "rich club hubs," connect larger number of brain regions over longer physical distances, often relayed through local hubs. It has been proposed that rich club hubs are important for large-scale and multi-modal integration of information. Other analytical methods, such as time-series fMRI, measure functional connectivity among brain regions by analyzing synchronization of activity. These analyses (Senden, Reuter, van den Heuvel, Goebel, Deco, and Gilson, 2018) indicate that rich club hubs have relatively stable functional connectivity to each other; in contrast, there is considerable variability in the functional connectivity between rich club hubs and peripheral brain regions.

Selective Attention

Another approach for effective cognition, related to broadcasting of information, is to focus processing on some incoming information at the expense of other information, i.e., typically termed selective attention (Dehaene, 2014, pp. 21–22; Yantis, 2008). Attention involves competitive interactions during inter-neuronal communications such that signalling from some neurons but not others are forwarded for processing (Moran and Desimone, 1985). Attentional mechanisms are at work during several stages of cognitive processing, both in the prefrontal cortex (Kim, Ährlund–Richter, Wang, Deisseroth, and Carlén, 2016), and in other brain regions (Rueda and Posner, 2013).

Memory

Effective processing is also made possible by memories of previous experiences. Creating rich associations is an integral part of forming memories as well as in retrieving them. Memories can be formed more efficiently when items are presented in a context, such as linked to imagery (Groninger, 1971), or in an emotional context (Yesavage, Rose, and Bower, 1983), as compared to an absence of these contexts. The hippocampus has a key role in forming associations, e.g., in linking a new item or event with information about its time and place (Mankin et al., 2012; Staresina and Davachi, 2009). The hippocampus has neural connections with several regions of the cortex, and these connections are regarded as important for integrated memories. During memory retrieval a single cue, such as a smell (Gottfried, Smith, Rugg, and Dolan, 2004), spatial cue (Karlsson and Frank, 2009), or words (Horner, Bisby, Bush, Lin, and Burgess, 2015), can bring back larger episodic memories. Cue-based recall of memory helps the processing of incoming sensory information.

Sensory-Decoupled Cognition

In addition to sensory-coupled cognition, cognitive processing can also involve content that is unrelated to immediate sensory input. Such sensory-decoupled processing (hereafter called "decoupled cognition") includes day dreaming, mind wandering, creative thinking, and rumination (Christoff, Irving, Fox, Spreng, and Andrews–Hanna, 2016). Research (Killingsworth and Gilbert, 2012; Klinger and Cox, 1987; Song and Wang, 2012) suggests that 20-50% of our time awake is spent mind wandering.

Decoupled cognition is not just abundant, it can also lead to important outcomes: planning for the future and achieving future goals (Stawarczyk, Majerus, Maj, Van der Linden, and Argembeau, 2011; Smallwood, Ruby, and Singer, 2013), reprocessing of memory (Wang et al. 2009), as well as creativity and problem solving (Beaty, Benedek, Silvia, and Schacter, 2016; Ritter and Dijksterhuis, 2014; Sio and Ormerod, 2009). Decoupled cognition can also have negative effects such as poorer performance of ongoing tasks (He et al., 2009; Stawarczyk et al., 2011) and unhappiness (Killingsworth and Gilbert, 2012). It has been proposed (Allen et al. 2013; Vatansever, Manktelow, Sahakian, Menon, and Stamatakis, 2016) that decoupled cognition has an overall positive impact on performance when it is flexibly balanced with sensory-coupled cognition.

Some brain regions, those of default mode network (Grecius, Krasnow, Reiss, and Menon, 2003; Mason et al., 2007), show preferential activation during decoupled cognition, but several other regions appear not to have such a preference. Many brain regions become activated when we plan for or are memorizing an event (decoupled processing) as well as when we experience something in real-time and perform motor action (sensory-coupled processing) [Barsalou, 2008, p. 627; Decety and Grèzes, 2006; Nyberg et al., 2000]. Because there are similarities between decoupled and sensory-coupled processing it has been suggested (Baars, 2010; Shanahan, 2006; Song and Tang, 2008) that the global workspace theory applies to both types of processing. This idea will be expanded upon in this paper.

Emotion

Multiple Functions of Emotions

Emotion is a central and complex part of consciousness that has been difficult to define. Izard (2010) proposed a description of emotion based on surveying the opinions of experts in the field: "Emotion consists of neural circuits (that are at least partially dedicated), response systems, and a feeling state/process that motivates and organizes cognition and action." This paper will view emotion as being an important part of the global workspace theory. Emotions are evoked by internal or external cues and result in different types of responses. A wide variety of functions are influenced by emotions, such as attention (Alpers and Gerdes, 2007; LoBue and DeLoache, 2008; Öhman, Flykt, and Esteves, 2001; Yoon, Hong, Joormann, and Kang, 2009), reasoning and decision making (Blanchette, 2006; De Martino, Kumaran, Seymore, and Dolan, 2006; Sohn et al., 2015; Zeelenberg, Nelissen, Breugelmans, and Pieters, 2008) as well as arousal and memory (Bradley et al., 1992; Cahill and McGaugh, 1995). It has been argued that emotions are an economical and effective means to respond to input in a beneficial way (Bach and Dayan, 2017; Bechara and Damasio, 2005; Muramatsu and Hanoch, 2005).

Appraisal as a Source of Emotions

One view is that emotions are caused by neural activity and can arise from both sensory-coupled (Alpers and Gerdes, 2007; Öhman et al., 2001) and decoupled processing (Killingsworth and Gilbert, 2012; Ruby, Smallwood, Engen, and Singer, 2013). The neural activity that gives rise to emotions can be more or less complex. On one hand, it is understood that the processing that gives rise to somatosensory sensations (e.g., pain and temperature) is less complex (Lloyd, McGlone, and Yosipovitch, 2015; Ross, 2011). On the other hand, many other emotions are caused by more complex processing. According to appraisal theories (Moors, Ellsworth, Scherer, and Frijda, 2013; Roseman and Smith, 2001), emotions arise from cognitive evaluation of events and situations. It has been proposed (Scherer, 2009; Scherer and Meuleman, 2013) that these evaluations involve appraisal of several categories (relevance, coping potential, normative significance; as well as their subcategories) and that, depending on how such categories score, specific emotions are evoked: joy, rage, fear, sadness. A similar idea, using a different scheme, was proposed by Roseman (2013). These hypotheses have received some experimental support. Scherer and Meuleman (2013) found that subjects' reports of their emotions correlated with the ratings they provided for different appraisal categories. Also, Roseman and Evdokas (2004) investigated how controlled manipulation of appraisals affects subjects' emotions. Four experimental groups were provided different instructions regarding food they were about to receive. These diverging instructions resulted in differences in how the groups appraised their situations, and also in the emotions they experienced.

A Modified Global Workspace Model for Consciousness

Figure 1 presents a model for cognitive processing that is based on the global workspace theory and shares some of its elements with the Router model and the LIDA model. During the first step, sensory input is received by local networks of parallel and layered processors, and these transform the incoming information. Such processing also involves the information being appraised, and, potentially, that emotions are evoked. Emotions lead to several types of responses and functions, e.g., to attention and access to short-term memory where information can be stored for several seconds (McGaugh, 2000). This short-term storage enables the information to be carried forward to subsequent rounds of processing. Attention also allows for access to network hubs as well as to long-term memories that can be retrieved and utilized for additional rounds of cognition. When information gains access to hubs, it becomes condensed. This condensation will result in some information being filtered away, and prevents the information from becoming conscious. The remaining condensed information gains access hubs where it is broadcasted and received by local networks. This closes one round of cognitive processing. Provided that the broadcasting is sufficiently widespread we will become conscious of the information.

Rich Club Hubs as Bottlenecks of Cognitive Processing

Conscious processing has a bottleneck — generally we are not conscious of several streams of information at the same time (Logothetis, Leopold, and Sheinberg, 1996; Pashler, 1994). There are indications (Dixon, Fox, and Christoff, 2015) that this bottleneck applies both to sensory-coupled processing and to decoupled processing.

There are reasons for believing that rich club hubs are primarily responsible for the bottleneck of conscious processing, and that this limitation is due to the burden of broadcasting information. Rich club hubs connect brain regions through

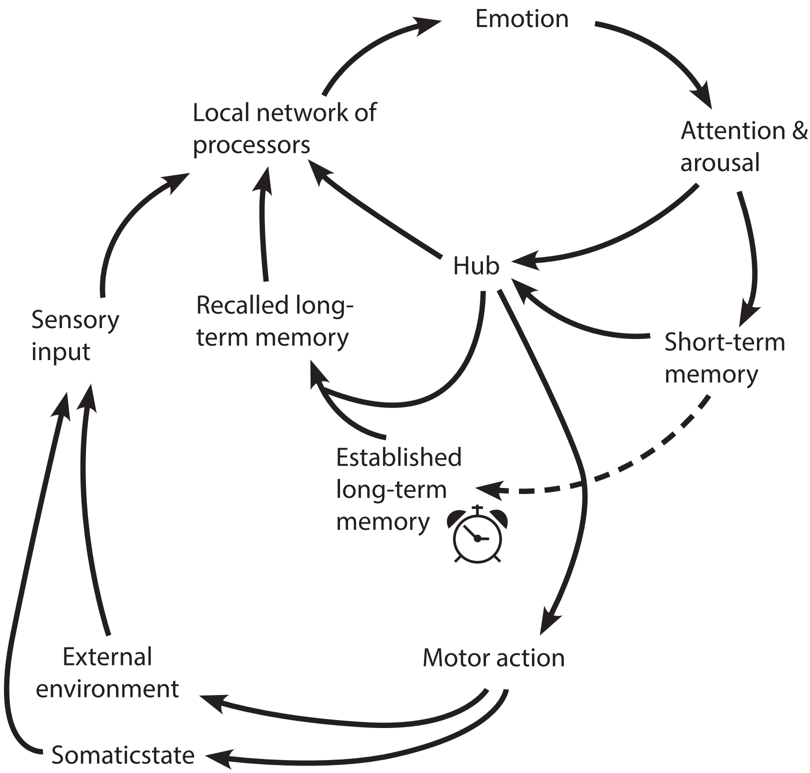

Figure 1: A proposed workflow model for cognitive processing. The figure illustrates how the different components of cognition interact to form feed-back loops. The arrows indicate sequential events during the step-wise processing of information. There is an exception to this step-wise progression: in rare cases (see the section "Emotions as Enablers of Cognitive Processing"), information may flow directly from "local networks of processors" to "hubs" by-passing "emotion" and "attention & arousal." The broken arrow and the clock indicate that it takes much longer to create "established long-term memory" than to complete other parts of the cognitive cycle.

long-distance axonal projections (Reardon, 2017; Rubinov, Ypma, Watson, and Bullmore, 2015). This mode of wiring is not as economical as utilizing a more distributed connectivity but it brings the advantages of adaptable and integrated processing (Bullmore and Sporns, 2012). Rich club hubs have been found to gate the information they receive (Senden, Reuter, van den Heuvel, Goebel, Deco, and Gilson, 2018), and this may be due to the cost of broadcasting. Analysis of gene expression also suggests there is cost; the transcriptional signature of rich club hubs indicates high metabolic activity (Fulcher and Fornito, 2016), exceeding that of several other neuronal structures (Vértes et al., 2016), suggesting that rich club hubs operate at a high capacity.

Emotions as Enablers of Cognitive Processing

If rich club hubs are the major bottleneck of conscious processing, then it becomes important to select the information that gains access to these hubs. This paper suggests that emotion is a key factor in enabling access to the global workspace. Results from fMRI studies (Costafreda, Brammer, David, and Fu, 2008; Goldin, Hutcherson, Ochsner, Glover, Gabrieli, and Gross, 2005; Stark, Schienle, Walter, Kirsch, Sammer, Ott, Blecker, and Vaitl, 2003; Zeki, Romaya, Benincasa, and Atiyah, 2014) are consistent with this idea: emotional stimuli induce a greater activation of brain regions that contain rich club hubs (e.g., amygdala, hippocampus, thalamus, and medial orbito-frontal cortex) than do non-emotional stimuli. Also, unique large-scale networks emerge when subjects experience different emotions (Kragel and LaBar, 2015; Saarimäki et al., 2016; Wager, Kang, Johnson, Nichols, Satpute, and Barrett, 2015).

Emotional stimuli not only induce network connectivity but also (perhaps as a consequence of altered connectivity) affect consciousness and attention. When subjects are presented with different visual inputs that compete for attention they become aware of emotional stimuli more often (Alpers and Gerdes, 2007; Yoon, Hong, Joormann, and Kang, 2009) and more rapidly (LoBue and DeLoache, 2008; Öhman, Flykt, and Esteves, 2001) than non-emotional stimuli. Also, there are different effects of emotional and non-emotional stimuli in rapid serial visual presentations (RSVP) experiments. In such experiments a first stimulus, T1, interferes with the ability to become aware of a second stimulus, T2. Most et al. (2005) found that a T1 stimulus causes more distraction on a T2 stimulus when T1 is emotional as compared to when it is non-emotional. Conversely, Anderson (2005) found that a T2 stimulus is better at overcoming distraction if it is emotional as compared to when T2 is neutral. Collectively, these studies indicate that non-emotional stimuli are less effective at creating attention and awareness than are emotional stimuli. Nevertheless, a non-emotional stimulus has the potential to induce consciousness but is likely to do so only if competing emotional stimuli are absent. Such conducive conditions exist in laboratories which are typically devoid of unintended emotional stimuli. I suggest this is generally not the case in real life situations where competing emotional stimuli are often present: environmental sampling studies (Carstensen, Pasupathi, Mayr, and Nesselroade, 2000; Trampe, Quoidbach, and Taquet, 2015; Zelensky and Larsen, 2000) indicate that we experience emotions during 90% of our normal daily lives. This implies that we are unlikely to become aware of non-emotional stimuli during 90% of our daily lives because, in those instances, emotional stimuli are present and they likely out-compete non-emotional stimuli.

Altogether, there is evidence that emotions help provide access to the global workspace and induce consciousness. Other global workspace-based models make similar proposals; they suggest that saliency, feelings (Franklin, Madl, D'Mello, and

Snaider, 2014; Franklin et al., 2016), and affect (Shanahan, 2005), are important for broadcasting information to the global workspace and for repeat processing.

A Heuristic Formula for the Sustainability of Cognitive Processing

In the proposed model (Figure 1) local networks of processors create emotions, promoting rich club hubs to broadcast information, enabling the information to undergo repeated rounds of processing. Different streams of information are processed at any given time by different local networks, and unrelated streams compete for access to the same rich club hubs. It is proposed that a given stream is likely to be sustained only if it generates sufficient emotion to be broadcast to a large enough number of local networks. If the number of networks that are engaged in repeat processing cannot be maintained, then that stream of processing will either stop or become diminished. In other words, it is proposed that sustainability is the amount of emotional intensity generated during processing compared to the cognitive effort required for such processing to continue, and this can be expressed as:

Sustainability of Processing = Emotional Intensity/Cognitive Effort

This formula should be seen as heuristic, describing an approximate relationship among three parameters that are on an ordinal scale. There are several methods for measuring cognitive effort, including electroencephalography (Antonenko, Paas, Grabner, and Van Gog, 2010), pupillometry (Kahneman and Beatty, 1966) and response time measurements (Dux et al., 2009; Smallwood, McSpadden, and Schooler, 2007). Also, a number of methods (reviewed by Mauss and Robinson, 2009) have been used for measuring different emotions. The next few sections will look at how this equation applies to different levels of consciousness. Briefly, it is proposed that different types of sensory input create different levels of emotional intensity and cognitive effort which results in different levels of cognitive processing that have different degrees of sustainability. These concepts will also be applied to decoupled processing.

Sensory-Coupled Processing

The Subliminal Level of Sensory-Coupled Processing

At this simplest level of consciousness, the brain receives sensory input but performs only cursory processing, i.e., input is processed by early sensory areas of the brain (Dehaene, 2014, pp. 121–123; Dehaene et al., 2006), but is not forwarded to other regions of the brain. This input has been described as having low stimulus strength (Dehaene et al., 2006). Here, such input is viewed as not generating significant emotion (Table 1, row 1) and, as a consequence, is not likely to undergo sustained processing. Subliminal stimuli have difficulty accessing

Table 1

Relationships between Properties of Input and Cognitive Processing

Row number	Level of consciousness	Properties of input and how it is processed			Sustainability of processing
		Familiarity	Emotional intensity	Cognitive effort	
1.	Subliminal	Low, medium or high	Negligible (0)	N/A	N/A
2.	Preconscious	High	Low (1)	Low (1)	1
3.	Conscious	Low, medium or high	High (4)	Medium (2)	2
4.	Meta-conscious	Medium or high	Medium to high (3)	High (4)	0.8

This table illustrates how different properties of input — and how such input is processed — lead to different degrees of sustainability of processing. This table applies to both sensory input (rows 1–3) as well as to decoupled input [memory] (rows 1–4). The three middle columns illustrate that input can have different degrees of familiarity, evoke different degrees of emotions and impart different cognitive efforts. Each of these different variables is ranked from negligible to high, corresponding to a scale of ordinal values ranging from zero to four. The sustainability of processing (right-most column) is calculated. Sustainability of Processing = Emotional Intensity/Cognitive Effort.

rich club hubs and are therefore unlikely to complete a first round of cognitive processing. Despite processing not being sustainable, it need not be completely non-productive. Short, subliminal exposure to an emotional (Winkielman and Berridge, 2004) or non-emotional (Naccache, Blandin, and Dehaene, 2002) stimuli has the capability to influence attention to a subsequent, consciously processed stimulus. However this influence requires that the timing between the two stimuli is very short (Naccache et al., 2002).

The Preconscious Level of Sensory-Coupled Processing

Preconsciousness is the next level of consciousness, and it is more capable than subliminal processing. One such capability is to store partially processed information while awaiting for access to conscious processing to become available. Some experimental set-ups (RSVP and psychological refractory period; reviewed by Dehaene et al. [2006]) provide strong evidence for this capability, and have lead to the view that preconscious processing is "conscious-in-waiting" (Dehaene, 2014, p. 191). The LIDA model provides a somewhat different view — it proposes that preconscious processing is ongoing and active, and that such activity underpins conscious processing (Franklin and Baars, 2010).

There are reasons to believe that preconscious processing is not limited to "consciousness-in-waiting" or provides support for conscious processing, but instead, that preconscious processing can also lead to functional outcomes. A number of activities can be performed preconsciously, including integration of multisensory information (Salomon et al., 2017), social signalling (Lakin and Chartrand, 2003), reading and performing additions (Sklar, Nevy, Goldstein, Mandel, Maril, and Hassin, 2012), decision making (Galdi, Arcuri, and Gawronski, 2008), and playing chess (Kiesel, Kunde, Berner, and Hoffmann, 2009). Since some of these processes are relatively complex, it seems reasonable that they involve multiple rounds of cognitive processing, i.e., that preconscious processing can be sustained.

The studies cited above describe mental operations that had been overlearnt through past events, and this is likely a hallmark for this type of preconscious processing. It has been claimed (Bargh, 1997) that automated processing is very common and that much of our everyday lives relies on learnt processes that are executed preconsciously. Overlearned processes have been well studied. When a cognitive task is performed regularly, it results in changes to neural structure (myelination) and routing (plasticity) [Chevalier et al., 2015; Mensch et al., 2015; O'Rourke, Gasperini, and Young, 2014]. Cellular changes can result in neurons responding more selectively and efficiently to specific stimuli (Baker, Behrmann, and Olson, 2002). At the macro-anatomical level, training results in reduced activation of fronto-parietal and other brain regions (Chein and Schneider, 2012; Dux et al., 2009; Garner and Dux, 2015). In other words, whereas the performance of a new task often requires wide-spread brain activation, training results in the same task being performed with far less broadcasting of information. The reduction in fronto-parietal activity could either be due to overlearnt processing not being highly dependent on these regions (Kelly and Garavan, 2005) or, alternatively, that extensive practise has led to fronto-parietal activity becoming more efficient (Dux et al., 2009; Garner and Dux, 2015).

The neural changes that occur during learning allow a task to be executed rapidly (Lee, Seo, and Jung, 2012) and also to be performed concurrently with other tasks (Dux et al., 2009; Garner and Dux, 2015). This suggests that the cognitive effort for processing is relatively low. Another important observation is that training often leads to a reduced emotional response (Carretié, Hinojosa, and Mercado, 2003; Fischer et al., 2003; Rankin et al., 2009). Assuming that both cognitive effort and emotional intensity are low (Table 1, row 2), one may calculate the sustainability for preconscious processing; as compared to other levels of consciousness (Table 1, rows 1-4), the preconscious level has an intermediate degree of sustainability.

The Conscious Level of Sensory-Coupled Processing

Conscious processing is characterized by being reportable, and as discussed above, by being effortful. Conscious processing is also seen as being more capable and flexible than preconscious processing, notably through the greater involvement of the prefrontal cortex (Daw, Niv, and Dayan, 2005; Eslinger and Grattan, 1993; Karnath and Wallesch, 1992). I suggest that emotional intensity is a key factor in determining whether sensory information will be processed consciously or not. It is commonly recognized that novel stimuli can give rise to intense emotions, and that novel stimuli tend to be processed consciously. However, conscious processing and intense emotions are not limited to novel stimuli; in some contexts, re-exposure to a stimulus results in a sensitised response (Grillon and Davis, 1997; Groves and Thompson, 1970; Richardson and Elsayed, 1998). These familiar stimuli are likely to be processed consciously. Assuming a conscious processing involves a relatively high emotional intensity and an intermediate level cognitive effort (Table 1, row 3), the sustainability of such processing would be greater than that of any other level of processing. This means that a stream of conscious processing is likely to be highly recursive and able to effectively compete with other streams.

Decoupled Processing

Different Levels of Decoupled Processing

In addition to sensory-coupled processing, cognitive processing can also be decoupled from immediate sensory input, i.e., rather than processing real-time sensory input, there is off-line processing, including reprocessing of past experiences and planning for future actions. This decoupled processing can compete with sensory-coupled processing for mental resources (reviewed by Kam and Handy, 2013; Smallwood and Schooler, 2006), and therefore, it is suggested that decoupled processing needs to be included as part of the global workspace theory. I propose that decoupled processing, like sensory-coupled processing, can have different levels of processing, a point also made by others. Moutard et al. (2015) argued that decoupled cognition can transition from being subliminal to becoming conscious. Also, it has been posited (Dixon, Fox, and Christoff, 2014) that decoupled processing, similar to sensory-coupled cognition, has a simpler level of processing that is not resource-demanding, as well as a higher level of processing that requires more resources. There is evidence that memories can induce decoupled processing (Ellamil et al., 2016). I suggest that processing of memories, similar to processing of real-time sensory information, can have different emotional intensity, cognitive effort, and sustainability, and that these different parameters determine the cognitive level at which memories are be processed. More specifically, I propose that the relationships outlined in Table 1 apply not only to sensory-coupled cognition but also to decoupled cognition.

Decoupled Processing: The Subliminal Level

The subliminal level of processing is not reportable; also it is short-lived and contained within local networks of the brain (Dehaene et al., 2006). There is reason to believe that some decoupled activity is subliminal, i.e., in the absence of known sensory input, there is temporary activation in isolated areas and small-world networks of the brain (He et al., 2009; Smith et al., 2012). This paper interprets decoupled subliminal activity as being the activation of memories that do not have a significant emotional content, and are therefore unlikely to complete a first round of cognitive processing.

Decoupled Processing: The Preconscious Level

Preconscious processing is also not reportable, and involves a modest degree of integration of different brain regions (Dehaene et al., 2006). There are indications that decoupled processing can be preconscious. After one has formulated a problem there may be an "incubation" phase before a solution is found. During this incubation phase (Hamard, 1954, pp. 13–15; Ritter and Dijksterhuis, 2014; Sio and Ormerod, 2009), we are not conscious of trying to solve a problem. However, that we can quite suddenly reach insight has been taken as an indication of preconscious processing. The literature has examples of complex tasks being processed preconsciously, e.g., executing higher mathematics, and this would presumably require multiple rounds of processing. I propose that this preconscious processing is caused by the activation of memories that have a low but significant emotional content and, as a result, are processed in a sustainable manner.

Decoupled Processing: The Conscious Level

Conscious processing is reportable and involves a high degree of integration among different brain regions (Dehaene et al., 2006). Decoupled consciousness, which is not constrained by real-time sensory information, has the potential of being highly flexible and dynamic. It is understood that an ongoing chain of decoupled thoughts is linked together through memories that share some aspects of their content (Gabora and Carbert, 2015; James, 1890, p. 243). Such serial linkages are important for creative thinking and problem resolution (Beaty, Benedek, Silvia, and Schacter, 2016; Ritter and Dijksterhuis, 2014; Sio and Ormerod, 2009). Not all forms of decoupled conscious processing are fluctuating and fluid — rumination is relatively rigid.

How can different forms of decoupled processing at the conscious level be understood in terms of the model proposed earlier in this paper (Table 1)? In the case of rumination there are often strong and persistent emotions (Thomsen, 2006). Also, rumination has limited content (Tanner, Voon, Hasking, and Martin, 2013) and there is usually no productive outcome; for these reasons I propose that rumination involves only a moderate cognitive effort. According to the proposed model a combination of moderate cognitive effort and high emotional intensity will result in sustainable cognitive processing (Table 1, row 3). This is consistent with observations — rumination is repetitive and persistent (Moberly and Watkins, 2008), and it is difficult to switch from rumination to other cognitive tasks (Curci, Lanciano, Soleti, and Rimé, 2013; Whitmer and Banich, 2007). There are indications that other forms of conscious decoupled processing also involve relatively high emotional intensity: daydreaming (Carr and Nielsen, 2015), relaxed wakefulness (Foulkes and Fleisher, 1975; Tusche, Smallwood, Bernhardt, and Singer, 2014) and creative thinking (Russ and Schafer, 2006). Also, similar to rumination, mind wandering can be highly sustainable since it can interfere with conscious sensory-coupled processing (Kam and Handy, 2013; Smallwood and Schooler, 2006). Based on this reasoning, it is proposed that decoupled consciousness, similar to sensory-coupled consciousness, has relatively high emotional intensity and high sustainability (Table 1, row 3).

Decoupled Processing: The Meta-Conscious Level

Meta-consciousness is seen as the highest level of processing, and it is reportable. Whereas other levels of consciousness involve processing (or reflecting) on items, events or concepts, meta-consciousness involves reflecting on thinking processes themselves. Schooler (2002, p. 339) defines meta-conscious processing as "intermittent explicit re-representations of the contents of consciousness."[3] There are several implications of this definition. First, in order to re-represent consciousness, meta-conscious processing must occur after conscious processing — a “temporal dissociation” (Schooler, 2002). This means that meta-consciousness is decoupled from sensory input and that there is no sensory-coupled level of meta-consciousness. Second, if meta-consciousness processing is the re-representation of consciousness then it is likely to pose a greater cognitive effort than does conscious processing. It has been found (reviewed by Schooler, 2002) that monitoring conscious content results in loss of information, consistent with the idea that meta-conscious monitoring demands more mental resources than does conscious experience. Another indication that meta-consciousness involves a high cognitive effort comes from studies concerning how it interferes with performance of an unrelated task. Smallwood, McSpadden, and Schooler (2007) found that mind wandering with awareness leads to longer response time of an unrelated task than does mind wandering without awareness. Third, it may be expected that re-representation (meta-consciousness) may lead to emotions becoming less vivid as compared to when they are directly experienced (consciousness). Research indicates that this can indeed be the case (Papies, Pronk, Keesman, and Barsalou, 2015; Schooler, Ariely, and Loewenstein, 2003, pp. 56–59; Shapira, Gundar–Goshen, and Dar, 2013): when participants are asked to observe their thoughts and responses to a positive stimulus or situation they rate their emotions as being less positive as compared to when they are instructed to simply experience the stimuli or situation.

If meta-consciousness involves less emotional intensity and a greater cognitive effort than does consciousness, then it will, according to the formula presented earlier, be less sustainable than consciousness (Table 1, row 3 versus row 4). There are indications that meta-conscious processing is indeed less sustainable than other forms of decoupled conscious processing: alcohol consumption (Sayette, Reichle, and Schooler, 2009), craving for cigarettes (Sayette, Schooler, and, Reichle, 2010) and sleep deprivation (Poh, Chong, and Chee, 2016) all reduce the proportion of mind wandering that involves awareness. Since these different experimental conditions had a greater impact on the occurrence of meta-consciousness than on decoupled consciousness, it is deemed that meta-consciousness is less sustainable than decoupled consciousness.

There is evidence that meta-consciousness can be productive, that the act of observing our conscious thoughts can influence how we think, feel, as well as the decisions we make. Hasenkamp et al. (2012) found that the act of catching oneself mind wandering is followed by attention being brought back to task performance, with task performance being resumed. Such an observation is consistent with

[3]Some publications use the term “mind wandering with awareness” rather than “meta-consciousness,” and this paper will use these terms interchangeably.

meta-consciousness exerting regulation on other cognitive processes. In another example, Papies et al. (2015) found that observing one's reactions to pictures of attractive food leads to changes in how subjects rated the attractiveness of different food. Also, in a separate extension of the same experiment, it was found that the subjects' choice of food purchase changed.

Son and Schwartz (2002) and Zelaso (2015) also argued that high-level processing can have productive outcomes. It has been proposed that executive control is exerted by high-level processes that re-represent/reflect on input (Son and Schwartz, 2002; Zelaso, 2015) and that are decoupled from sensory input (Stanovich, 2009). It appears that meta-consciousness processing has dual properties. On one hand, it is not very sustainable and, on the other hand, once meta-conscious processing does occur, it has the ability to influence many other mental processes.

Discussion

Advantages and Limitations of the Proposed Model

This paper builds on the global workspace theory proposed by Baars (Baars, 1997, 2005; Baars, Franklin, and Ramsoy, 2013) and elaborated by Dehaene (Dehaene et al., 2006; Zylberberg et al., 2010, 2011), Franklin (Franklin et al., 2014, 2016) and their colleagues. The model presented in this paper explains how different levels of consciousness are sustained. Sustained processing is important for solving complex problems and for creating a rich, dynamic understanding of our surroundings. In addition, this paper describes how decoupled processing can be incorporated into the same general model as sensory-coupled processing. Such a common framework might simplify and help provide a coherent understanding of these two types of processing.

Essentially, the proposed model states a stimulus is likely to undergo sustained cognitive processing if it produces significant emotions and imparts a small cognitive effort. Also the model proposes that different levels of consciousness are characterized by different degrees of emotional intensity and cognitive effort. This model has its limitations. First, additional experiments are needed to assess the validity of the model, particularly for decoupled processing at the subliminal and preconscious levels. It is difficult to perform controlled experiments with these levels of processing since the levels occur spontaneously and are not reportable; therefore new experimental designs may be needed. There are empirical data for other levels of processing, but I have not found studies that measure all parameters of interest (emotion, cognitive effort, and sustainability) in the same experiment. The proposed model is based on studies that measure only one or two of these parameters at a time. Measuring all three parameters simultaneously would help assess the validity of the proposed model. Second, the model proposes that each level of processing has a distinct ordinal value for emotional intensity, cognitive effort, and sustainability (Table 1). It is possible that once more experimental data become available that some heterogeneity is discovered within each level of processing. Third, the paper presents a relatively simple conceptual model and, unlike the Router and LIDA models, it has not yet been translated into an elaborate computer architecture.

What are Different Levels of Consciousness Good For?

If the presented model is essentially correct, then what would be the utility for regulating the different levels of processing as described? There is a trend when comparing the three simplest levels of consciousness, subliminal, preconscious, and conscious processing: for each higher level of processing the input receives increasingly higher emotional appraisal, leading to greater access to the global workspace and to higher sustainability of processing. This trend appears to make sense — that large amounts of mental resources are dedicated to tasks that (through emotional appraisal) are deemed to be highly relevant and important, and that the processing of these tasks becomes sustainable. This paper proposes that such a principle applies to both sensory-coupled and to decoupled processing; that allocation of resources applies not just to how we process large amounts of information about a real-time situation (sensory-coupled processing), but also to how we plan for future actions and how we solve problems off-line by retrieving information from the brain's vast memory banks (decoupled processing)

Peculiarly, the highest level of processing, meta-consciousness, does not fully conform to the trends seen for the three simpler levels of processing (Table 1). Emotional intensity, cognitive effort, and sustainability increase in the order subliminal < preconscious < conscious processing. However, only cognitive effort increases when comparing the highest two levels, conscious < meta-conscious. The other two parameters, emotional intensity and sustainability, are lower at the meta-conscious level than at the conscious level.

What would be the utility of meta-consciousness having less sustainability than consciousness? This may relate to the idea that meta-consciousness has the ability to regulate other cognitive processes. If the primary utility of meta-consciousness was to exert a regulatory function, and it had no direct role in processing input, it may be best if it was not too sustainable; if meta-consciousness was brief, then most of our mental resources could be spent on actual processing of input, and only limited resources could be spent on regulating such processing.

References

Anderson, A.K. (2005). Affective influences on the attentional dynamics supporting awareness. *Journal of Experimental Psychology*: *General, 134,* 258–281. doi: 10.1037/0096-3445.134.2.258

Antonenko, P., Paas, F., Grabner, R., and Van Gog, T. (2010). Using electroencephalography to measure cognitive load. *Educational Psychology Review*, *22*(4), 425–438. doi: 10.1007/s10648-010-9130-y
Allen, M., Smallwood, J., Christensen, J., Gramm, D., Rasmussen, B., Jensen, C.G., Roepstorff, A., and Lutz, A. (2013). The balanced mind: The variability of task-unrelated thoughts predicts error monitoring. *Frontiers in Human Neuroscience, 7*, 743. doi: 10.3389/fnhum.2013.00743
Alpers, G.W., and Gerdes, A.B.M. (2007). Here is looking at you: Emotional faces predominate in binocular rivalry. *Emotion, 7*, 495–506. doi: 10.1037/1528-3542.7.3.495
Baars, B.J. (1997). In the theatre of consciousness: Global Workspace Theory, a rigorous scientific theory of consciousness. *Journal of Consciousness Studies, 4,* 292–309.
Baars, B.J. (2005). Global workspace theory of consciousness: Toward a cognitive neuroscience of human experience? *Progress in Brain Research, 150*, 45–53. doi: 10.1016/S0079-6123(05)5000-9
Baars, B.J. (2010). Spontaneous repetitive thoughts can be adaptive: Postscript on McKay and Vane (2010). *Psychological Bulletin*, *136*, 208–221. doi: 10.1037/a0018726
Baars, B.J., Franklin, S., and Ramsoy, T.Z. (2013). Global workspace dynamics: Cortical "binding and propagation" enables conscious content. *Frontiers in Psychology*, *4,* 200. doi: 10.3389/fpsyg.2013.00200
Bach, D.R., and Dayan, P. (2017). Algorithms for survival: A comparative perspective on emotions. *Nature Reviews Neuroscience*, *18,* 311–319. doi:10.1038/nrn.2017.35
Baker, C.I., Behrmann, M., and Olson, C.R. (2002). Impact of learning on representation of parts and wholes in monkey inferotemporal cortex. *Nature Neuroscience, 5*, 1210–1216. doi:10.1038/nn960
Bargh, J.A. (1997). The automaticity of everyday life. In R.S. Wyer, Jr. (Ed.), *Advances in social cognition, volume 10. The automaticity of everyday life* (pp. 1–62). New York: Lawrence Erlbaum.
Bargh, J.A., and Morsella, E. (2008). The unconscious mind. *Perspectives on Psychological Science, 3*, 73–79. doi: 10.1111/j.1745-6916.2008.00064.x
Barsalou, L.W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617–645. doi: 10.1146/annurev.psych.59.103006.093639
Beaty, R.E., Benedek, M., Silvia, P.J., and Schacter, D.L. (2016). Creative cognition and brain network dynamics, *Trends in Cognitive Sciences, 20,* 87–95. doi: 10.1016/j.tics.2015.10.004
Bechara, A., and Damasio, A.R. (2005). The somatic marker hypothesis: A neural theory of economic decision. *Games and Economic Behavior, 52*, 336–372. doi: 10.1016/j.geb.2004.06.010
Bekinschtein, T.A., Dehaene, S., Rohaut, B., Tadel, F., Cohen, L., and Naccache, L. (2009). Neural signatures of the conscious processing of auditory regularities. *Proceedings of the National Academy of Sciences, USA*, *106*, 1672–1677. doi: 10.1073/pnas.0809667106
Blanchette, I. (2006). The effect of emotion on interpretation and logic in a conditional reasoning task. *Memory & Cognition*, *34*, 1112–1125. doi: 10.3758/BF03193257
Bola, M., and Sabel, B.A. (2015). Dynamic reorganization of brain functional networks during cognition. *Neuroimage, 114*, 398–413. doi: 10.1016/j.neuroimage.2015.03.057
Bradley, M.M., Greenwald, M.K., Petry, M.C., and Lang, P.J. (1992). Remembering pictures: Pleasure and arousal in memory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 18*, 379–390.
Bullmore, E., and Sporns, O. (2012). The economy of brain network organization. *Nature Reviews Neuroscience*, *13*, 336–349. doi: 10.1038/nrn3214
Cahill, L., and McGaugh, J.L. (1995). A novel demonstration of enhanced memory associated with emotional arousal. *Consciousness and Cognition*, *4*, 410–421. doi: 10.1006/ccog.1995.1048
Carr, M., and Nielsen T. (2015). Daydreams and nap dreams: Content comparisons. *Consciousness and Cognition*, *36*, 196–205. doi: 10.1016/j.concog.2015.06.012
Carretié, L., Hinojosa, J.A., and Mercado, F. (2003). Cerebral patterns of attentional habituation to emotional stimuli. *Psychophysiology*, *40*, 381–388. doi: 10.1111/1469-8986.00041
Carstensen, L.L., Pasupathi, M., Mayr, U., and Nesselroade, J.R. (2000). Emotional experience in everyday life across the adult life span. *Journal of Personality and Social Psychology*, *79*, 644–655. doi: 10.1037/0022–3514.79.4.644
Chein, J.M., and Schneider, W. (2012). The brain's learning and control architecture. *Current Directions in Psychological Science*, *21*, 78–84. doi: 10.1177/0963721411434977
Chevalier, N., Kurth, S., Doucette, M.R., Wiseheart, M., Deoni, S.C.L., Dean III, D.C., O'Muircheartaigh, J., Blackwell, K.A., Munakata, Y., and LeBourgeois, M.K. (2015). Myelination is associated with processing speed in early childhood: Preliminary insights. *PLoS One, 10,* e0139897. doi: 10.1371/journal.pone.0139897

Christoff, K., Irving, Z.C., Fox, K.C.R., Spreng, R.N., and Andrews–Hanna, J.R. (2016). Mind-wandering as spontaneous thought: A dynamic framework. *Nature Reviews Neuroscience*, *17*, 718–731. doi: 10.1038/nrn.2016.113

Cisek, P., and Kalaska, J.F. (2010). Neural mechanisms for interacting with a world full of action choices. *Annual Review of Neuroscience*, *33*, 269–298. doi: 10.1146/annurev.neuro.051508.135409

Costafreda, S.G., Brammer, M.J., David, A.S., and Fu, C.H.Y. (2008). Predictors of amygdala activation during the processing of emotional stimuli: A meta-analysis of 385 PET and fMRI studies. *Brain Research Review*, *58*, 57–70. doi: 10.1016/j.brainresrev.2007.10.012

Curci, A., Lanciano, T., Soleti, E., and Rimé, B. (2013). Negative emotional experiences arouse rumination and affect working memory capacity. *Emotion*, *13,* 867–880. doi: 10.1037/a0032492

Daw, N.D., Niv, Y., and Dayan, P. (2005). Uncertainty-based competition between prefrontal and dorsolateral striatal systems for bevioural control. *Nature Neuroscience*, *8*, 1704–1711. doi: 10.1016/j.brainresrev.2007.10.012

De Martino, B., Kumaran, D., Seymore, B., and Dolan, R.J. (2006). Frames, biases and rational decision-making in the human brain. *Science*, *313*, 684–687. doi: 10.1126/science.1128356

Decety, J., and Grèzes, J. (2006). The power of simulation: Imagining one's own and other's behavior. *Brain Research*, *1079*, 4–14. doi: 10.1016/j.brainres.2005.12.115

Dehaene, S. (2014). *Consciousness and the brain. Deciphering how the brain codes our thoughts.* New York: Penguin Books.

Dehaene, S., Changeux, J., Naccache, L. Sackur, J., and Sergent, C. (2006). Conscious, preconscious, and subliminal processing: A testable taxonomy. *Trends in Cognitive Sciences*, *10*, 204–211. doi: 10.1016/j.tics.2006.03.007

Dehaene, S., Naccache, L., Cohen, L., Le Bihan, D., Mangin, J., Poline, J., and Rivière, D. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience*, *4*, 752–758. doi: 10.1038/89551

Dehaene, S., and Sigman, M. (2012). From a single decision to a multi-step algorithm. *Current Opinion in Neurobiology*, *22*, 937–945. doi: 10.1016/j.conb.2012.05.006

Dixon, M.L., Fox, K.C.R., and Christoff, K. (2014). A framework for understanding the relationship between externally and internally directed cognition. *Neurophyschologia*, *62*, 321–330. doi: 10.1016/j.neuropsychologia.2014.05.024

Dux, P.E., Tombu, M.N., Harrison, S., Rogers, B.P., Tong, F., and Marois, R. (2009). Training improves multitasking performance by increasing the speed of information processing in human prefrontal cortex. *Neuron*, *63*, 127–138. doi: 10.1016/j.neuron.2009.06.005

Ellamil, M., Fox, K.C.R., Dixon, M.L., Pritchard, S., Todd, R.M., Thompson, E., and Christoff, K. (2016). Dynamics of neural recruitment surrounding the spontaneous arising of thoughts in experienced mindfulness practitioners. *NeuroImage*, *136*, 186–196. doi: 0.1016/j.neuroimage.2016.04.034

Eslinger, P.J., and Grattan, L.M. (1993). Frontal lobe and frontal-striatal substrates for different forms of human cognitive flexibility. *Neuropsychologia, 31,* 17–28. doi: 10.1016/0028-3932(93)90077-D

Faghihi, U., Estey, C., McCall, R., and Franklin S. (2015). A cognitive model fleshes out Kahnemann's fast and slow systems. *Biologically Inspired Cognitive Architectures*, *11*, 38–52. doi: 10.1016/j.bica.2014.11.014

Fahrenfort, J.F., Snijders, T.M., Heinen, K., Van Gaal, S., Scholte, H.S., and Lamme, V.A.F. (2012). Neuronal integration in visual cortex elevates face category tuning to conscious face perception. *Proceedings of the National Academy of Sciences, USA*, *109*, 21504–21509. doi: 10.1073/pnas.1207414110

Feldman, J.A., and Ballard, D.H. (1982). Connectionist models and their properties. *Cognitive Science, 6*, 205–254. doi: 10.1207/s15516709cog0603_1

Fischer, H., Wright, C.I., Whalen, P.J., McInerney, S.C., Shin, L.M., and Rauch, S.L. (2003). Brain habituation during repeated exposure to fearful and neutral faces: A functional MRI study. *Brain Research Bulletin*, *59*, 387–392. doi: 10.1016/S0361-9230(02)00940-1

Foulkes, D., and Fleisher, S. (1975). Mental activity in relaxed wakefulness. *Journal of Abnormal Psychology*, *84*, 66–75. doi: 10.1037/h0076164

Franklin, S., and Baars, B.J. (2010). Two varieties of unconscious processes. In E. Perry, D. Collerton, F. LeBeau, and H. Ashton (Eds.), *New horizons in the neuroscience of consciousness* (pp. 91–102). Amsterdam: John Benjamins Publishing Company.

Franklin, S., Madl, T., D'Mello, S., and Snaider, J. (2014). LIDA: A systems-level architecture for cognition, emotion and learning. *IEE Transactions on Autonomous Mental Development*, *6*, 19–41. doi: 10.1109/TAMD.2013.2277589

Franklin, S., Madl, T., Strain, S., Faghihi, U., Dong, D., Kugele, S., Snaider, J., Agrawal, P., and Chen, S. (2016). A LIDA cognitive model tutorial. *Biologically Inspired Cognitive Architectures*, *16*, 105–130. doi: 10.1016/j.bica.2016.04.003

Fulcher, B.D., and Fornito, A. (2016). A transcriptional signature of hub connectivity in the mouse connectome. *Proceedings of the National Academy of Sciences, USA*, *113*, 1435–1440. doi: 10.1073/pnas.1513302113

Gabora, L., and Carbert, N. (2015, July). A study and preliminary model of cross-domain influences on creativity. In R. Dale, C., Jennings, P., Maglio, T. Matlock, D. Noelle, A. Warlaumont, and J. Yashimi (Eds), *Proceedings of the 37th Annual Meeting of the Cognitive Science Society*. Conference at Austin, Texas.

Galdi, S., Arcuri, L., and Gawronski, B. (2008). Automatic mental associations predict future choices of undecided decision-makers. *Science*, *321*, 1100–1102. doi: 0.1126/science.1160769

Garner, K.G., and Dux, P.E. (2015). Training conquers multitasking cost by dividing task representations in the frontoparietal-subcortical system. *Proceedings of the National Academy of Sciences, USA*, *112*, 14372–14377. doi: 10.1073/pnas.1511423112

Geldard, F.A., and Sherrick, C.E. (1972). The cutaneous "rabbit": A perceptual illusion. *Science*, *178*, 178–179. doi: 10.1126/science.178.4057.178

Godwin, D., Barry, R.L., and Marois, R. (2015). Breakdown of the brain's functional network modularity with awareness. *Proceedings of the National Academy of Sciences, USA*, *112*, 3799–3804. doi: 10.1073/pnas.1414466112

Goldin, P.R., Hutcherson, C.A.C., Ochsner, K.N., Glover, G.H., Gabrieli, J.D.E., and Gross, J.J. (2005). The neural bases of amusement and sadness: A comparison of block contrast and subject-specific emotion intensity regression approaches. *NeuroImage*, *27*, 26–36. doi: 10.1016/j.neuroimage.2005.03.018

Gottfried, J.A., Smith, A.P.R., Rugg, M.D., and Dolan, R.J. (2004). Remembrance of odors past: Human olfactory cortex in cross-modal recognition memory. *Neuron*, *42*, 687–695. doi: 10.1016/S0896-6273(04)00270–3.

Grecius, M.D., Krasnow, B., Reiss, A.L., and Menon, V. (2003). Functional connectivity in the resting brain: A network analysis of the default mode hypothesis. *Proceedings of the National Academy of Sciences, USA, 100*, 235–258. doi: 10.1073/pnas.0135058100

Grillon, C., and Davis, M. (1997). Fear-potentiated startle conditioning in humans: Explicit and contextual cue conditioning following paired versus unpaired training. *Psychophysiology*, *34*, 451–458. doi: 10.1111/j.1469-8986.1997.tb02389.x

Groninger, L.D. (1971). Mnemonic imagery and forgetting. *Psychonomic Science*, *17*, 161–163. doi: 10.3758/BF03336531

Groves, P.M., and Thompson, R.F. (1970). Habituation: A dual-process theory. *Psychological Review*, *77*, 419–450. doi: 10.1037/h0029810

Hamard, J. (1954). *The psychology of inventions in the mathematical field*. New York: Dover Publications.

Hasenkamp, W., Wilson−Mendenhall, C.D., Duncan, E., and Barsalou, L.W. (2012). Mind wandering and attention during focused meditation: A fine-grained temporal analysis of fluctuating cognitive states. *NeuroImage, 59*, 750–760. doi: 10.1016/j.neuroimage.2011.07.008

He, Y., Wang, J., Wang, L., Chen, Z.J., Yan, C., Yang, H., Tang, H. Zhu, C., Gong, Q., Zang, Y., and Evans, A.C. (2009). Uncovering intrinsic modular organization of spontaneous brain activity in humans. *PLoS One*, *4,* e5226. doi: 0.1371/journal.pone.0005226

Hinton, G.E. (2007). Learning multiple layers of representation. *Trends in Cognitive Sciences*, *11*, 428–434. doi: 10.1016/j.tics.2007.09.004

Horner, A.J., Bisby, J.A., Bush, D., Lin, W., and Burgess, N. (2015). Evidence for holistic episodic recollection via hippocampal pattern completion. *Nature Communications*, *6*, 7462. doi: 10.1038/ncomms8462

Izard, C.E. (2010). The many meanings/aspects of emotion: Definitions, functions, activation and regulation. *Emotion Review*, *2*, 363–370. doi: 10.1177/1754073910374661

James, W. (1890). *The principles of psychology*. New York: Holt and Company.

Kahneman, D., and Beatty, J. (1966). Pupil diameter and load on memory. *Science*, *154*, 1583–1585. doi: 10.1126/science.154.3756.1583

Kam, J.W.Y., and Handy, T.C. (2013). The neurocognitive consequences of the wandering mind: A mechanistic account of sensory-motor decoupling. *Frontiers in Psychology, 4,* 725. doi: 10.3389/fpsyg.2013.00725

Karlsson, M.P., and Frank, L.M. (2009). Awake replay of remote experiences in the hippocampus. *Nature Neuroscience*, *12*, 913–918. doi: 10.1038/nn.2344

Karnath, H.O., and Wallesch, C.W. (1992). Inflexibility of mental planning: A characteristic disorder with frontal lobe lesions? *Neurophysiologa*, *30*, 1011–1016. doi: 10.1016/0028-3932(92)90052-N

Kelly, A.M.C., and Garavan, H. (2005). Human functional neuroimaging of brain changes associated with practise. *Cerebral Cortex*, *15*, 1089–1102. doi: 10.1093/cercor/bhi005

Kiesel, A., Kunde, W., Berner, M.P., and Hoffmann, J. (2009). Playing chess unconsciously. *Journal of Experimental Psychology: Learning, Memory and Cognition, 35*, 292–298. doi: 10.1037/a0014499

Killingsworth, M.A., and Gilbert, D.T. (2012). A wandering mind is an unhappy mind. *Science*, *330*, 932. doi: 10.1126/science.1192439

Kim, H., Ährlund–Richter, S., Wang, X., Deisseroth, K., and Carlén, M. (2016). Prefrontal parvalbumin neurons in control of attention. *Cell*, *164*, 208–218. doi: 10.1016/j.cell.2015.11.038

Klinger, E., and Cox, C.W. (1987). Dimensions of thought in everyday life. *Imagination, Cognition and Personality*, *7*, 105–128. doi: 10.2190/7K24-G343-MTQW-115V

Kolers, P.A., and von Grünau, M. (1975). Shape and color in apparent motion. *Vision Research*, *16*, 329–335. doi: 10.1016/0042-6989(76)90192-9

Kragel, P.A., and LaBar, K.S. (2015). Multivariate neural biomarkers of emotional states are categorically distinct. *Social Cognitive and Affective Neuroscience*, *10*, 1437–1448. doi: 10.1093/scan/nsv032

Lakin, J.L., and Chartrand, T.L. (2003). Using nonconscious behavioral mimicry to create affiliation and rapport. *Psychological Science*, *14*, 334–339. doi: 10.1111/1467-9280.14481

Lee, D., Seo, H., and Jung, M.W. (2012). Neural basis of reinforcement learning and decision making. *Annual Review of Neuroscience*, *35*, 287–308. doi: 10.1146/annurev-neuro-062111-150512

Lee, K.H., Mathews, P.J., Reeves, A.M.B, Choe, K.Y., Jami, S.A., Serrano, R.E., and Otis, T.S. (2015). Circuit mechanisms underlying motor memory formation in the cerebellum. *Neuron*, *86*, 529–540. doi: 10.1016/j.neuron.2015.03.010

Lloyd, D.M., McGlone, F.P., and Yosipovitch, G. (2015). Somatosensory pleasure circuitry: From skin to brain and back. *Experimental Dermatology*, *24*, 321–324. doi: 10.1111/exd.12639

LoBue, V., and DeLoache, J.S. (2008). Detecting the snake in the grass. Attention to fear-relevant stimuli by adults and young children. *Psychological Science*, *19*, 284–289. doi: 10.1111/j.1467–9280.2008.02081.x

Logothetis, N.K., Leopold, D.A., and Sheinberg, D.L. (1996). What is rivalling during binocular rivalry? *Nature*, *380*, 621–624. doi: 10.1038/380621a0

Mankin, E.A., Sparks, F.T., Slayeh, B., Sutherland, R.J., Leutgebb, S., and Leutgeb, J.K. (2012). Neuronal code for extended time in the hippocampus. *Proceedings of the National Academy of Sciences, USA, 109*, 19462–19467. doi: 10.1073/pnas.1214107109

Mason, M.F., Norton, M.I., Van Horn, J.D., Wegner, D.M., Grafton, S.T., and Macrae, C.N. (2007). Wandering minds: The default network and stimulus-independent thought. *Science*, *315*, 393–395. doi: 10.1126/science.1131295

Mauss, I.B., and Robinson, M.D. (2009). Measures of emotion: A review. *Cognition and Emotion*, *23*, 209–237. doi: 10.1080/02699930802204677

McGaugh, J.L. (2000). Memory — a century of consolidation. *Science*, *287*, 248–251. doi: 10.1126/science.287.5451.248

Melchers, D., and Morrone, C. (2007). Transsaccadic memory: Building a stable world from glance to glance. In R.P.G. Van Gompel, M.H. Fischer, W.S. Murray, and R.L. Hill (Eds.), *Eye movements: A window on mind and brain* (pp. 213–233). Oxford, United Kingdom: Elsevier.

Mensch, S., Baraban, M. Almeida, R., Czopka, T. Ausborn, J., El Manira, A., and Lyons, D.A. (2015). Synaptic vesicle release regulates the number of myelin sheaths of individual oligodendrocytes in vivo. *Nature Neuroscience*, 18, 628–630. doi: 10.1038/nn.3991

Moberly, N.J., and Watkins, E.R. (2008). Ruminative self-focus and negative affect: An experience sampling study. *Journal of Abnormal Psychology, 117,* 314–323. doi:10.1037/0021-843X.117.2.314

Moon, J., Lee, U., Blain–Moraes, S., and Mashour, G.A. (2015). General relationship of global topology, local dynamics, and directionality in large-scale networks. *PLoS Computational Biology, 11*, e1004225. doi: 10.1371/journal.pcbi.1004225

Moors, A., Ellsworth, P.C., Scherer, K., and Frijda, N. (2013). Appraisal theories of emotion: State of the art and future development. *Emotion Review, 5*, 119–124. doi: 10.1177/1754073912468165

Moran, J., and Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. *Science, 229,* 782–784. doi: 10.1126/science.4023713

Most, S.B., Chun, M.M., Widders, D.M., and Zald, D.H. (2005). Attentional rubbernecking: Cognitive control and personality in emotion-induced blindness. *Psychonomic Bulletin & Review*, *12*, 654–661. doi: 10.3758/BF03196754

Moutard, C., Dehaene, S., and Malach, R. (2015). Spontaneous fluctuations and non-linear ignitions: Two dynamic faces of cortical recurrent loops. *Neuron*, *88*, 194–206. doi: 10.1016/j.neuron.2015.09.018

Muramatsu, R., and Hanoch, Y. (2005). Emotions as a mechanism for boundedly rational agents: The fast and frugal way. *Journal of Economic Psychology*, *26*, 201–223. doi: 10.1016/j.joep.2004.03.001

Naccache, L., Blandin, E., and Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science*, *13*, 416–424. doi: 10.1111/1467-9280.00474

Nassi, J.J., and Callaway, E.M. (2009). Parallel processing strategies of the primate visual system. *Nature Reviews Neuroscience*, *10*, 360–372. doi: 10.1038/nrn2619

Nyberg, L., Habib, R., McIntosh, A.R., and Tulving, E. (2000). Reactivation of encoding-related brain activity during memory retrieval. *Proceedings of the National Academy of Sciences, USA, 97*, 11120–11124. doi: 10.1073/pnas.97.20.11120

Öhman, A., Flykt, A., and Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology*, *130*, 466–478. doi: 10.1037/AXJ96-3445.130.3.466

O'Rourke, M., Gasperini, R., and Young, K.M. (2014). Adult myelination: Wrapping up neuronal plasticity. *Neural Regeneration Research*, *9*, 1261–1264. doi: 10.4103/1673-5374.137571

Papies, E.K., Pronk, T.M, Keesman, M., and Barsalou, L.W. (2015). The benefits of simply observing: Mindful attention modulates the link between motivation and behavior. *Journal of Personality and Social Psychology*, *108*, 148–170. doi: 10.1037/a0038032

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin*, *116*, 220–244. doi: 10.1037/0033-2909.116.2.220

Poh, J., Chong, P.L.H., and Chee, M.W.L. (2016). Sleepless night, restless mind: Effects of sleep deprivation on mind wandering. *Journal of Experimental Psychology: General*, *145*, 1312–1318. doi: 10.1037/xge0000207

Poggio, T. (2016). Brain-inspired intelligent robotics: The intersection of robotics and neuroscience sciences. Deep learning: Mathematics and neuroscience [Supplementary booklet]. *Science, 354*, 9–12. doi: 10.1126/science.354.6318.1445-b

Rankin, C.H., Abrams, T., Barry, R.J., Bhatnagar, S., Clayton, D.F., Colombo, J., Coppola, G., Geyer, M.A., Glanzman, D.L, Marsland, S., McSweeney, F.K., Wilson, D.A., Wu, C., and Thompson, R.F. (2009). Habituation revisited: An updated and revised description of the behavioral characteristics of habituation. *Neurobiology of Learning and Memory*, *92*, 135–138. doi: 10.1016/j.nlm.2008.09.012

Reardon, S. (2017). Giant neuron encircles entire brain of a mouse. *Nature, 543*, 14–15. doi: 10.1038/nature.2017.21539

Richardson, R., and Elsayed, H. (1998). Shock sensitization of startle in rats: The role of contextual conditioning. *Behavioral Neuroscience*, *112*, 1136–1141. doi: 10.1037/0735-7044.112.5.1136

Rigas, P., and Castro–Alamancos, M.A. (2007). Thalamocortical up states: Differential effects of intrinsic and extrinsic cortical inputs on persistent activity. *Journal of Neuroscience, 27*, 4261–4272. doi: 10.1523/JNEUROSCI.0003-07.2007

Ritter, S.M., and Dijksterhuis, A. (2014). Creativity — the unconscious foundations of the incubation period. *Frontiers in Human Neuroscience*, *8*, 215. doi: 10.3389/fnhum.2014.00215

Roseman, I.J. (2013). Appraisal in the emotion system: Coherence in strategies for coping. *Emotion Review*, *5*, 141–149. doi: 10.1177/1754073912469591

Roseman, I.J., and Evdokas, A. (2004). Appraisals cause experienced emotions: Experimental evidence. *Cognition and Emotion*, *18*. 1–28. doi: 10.1080/02699930244000390

Roseman, I.J., and Smith, C.A. (2001). Appraisal theory. Overview, assumptions, varieties, controversies. In K.R. Scherer, A. Schorr, and T. Johnstone (Eds.), *Appraisal processes in emotion: Theory, methods and research* (pp. 3–19). New York: Oxford University Press.

Ross, S.E. (2011). Pain and itch: Insights into the neuronal circuits of aversive somatosensation in health and disease. *Current Opinion in Neurobiology 21*, 1–8. doi: 10.1016/j.conb.2011.10.012

Rubinov, M., Ypma, R.J.F., Watson, C., and Bullmore, E.T. (2015). Wiring cost and topological participation of the mouse brain connectome. *Proceedings of the National Academy of Sciences, USA, 112*, 10032–10037. doi: 10.1073/pnas.1420315112

Ruby, F.J.M., Smallwood, J., Engen, H., and Singer, T. (2013). How self-generated thought shapes mood — the relation between mind-wandering and mood depends on the social–temporal content of thoughts. *PLoS One, 8,* e77554. doi: doi.org/10.1371/journal.pone.0077554

Rueda, M.R., and Posner, M.I. (2013). Development of attention networks (pp. 683–705). In P.D. Zelato (Ed.), *The Oxford handbook of developmental psychology, Volume 1: Body and mind,* Chapter 24. doi: 10.1093/oxfordhb/9780199958450.013.0024

Russ, S.W., and Schafer, E.D., (2006). Affect in fantasy play, emotion in memories, and divergent thinking. *Creativity Research Journal*, 18, 347–354. doi: 10.1207/s15326934crj1803_9

Saarimäki, H., Gotsopoulos, A., Jääskeläinen, I.P., Lampinen, J., Vuilleumier, P., Hari, R., Sams, M., and Nummenmaa, L. (2016). Discrete neural signatures of basic emotions. *Cerebral Cortex*, 26, 2563–2573. doi: 10.1093/cercor/bhv086

Salomon, R., Noel, J., Łukowska, M., Faivre, N., Metzinger, T., Serino, A., and Blanke, O. (2017). Unconscious integration of multisensory bodily inputs in the peripersonal space shapes bodily self-consciousness. *Cognition, 166*, 174–183. doi: 10.1016/j.cognition.2017.05.028

Sayette, M.A., Reichle, E.D., and Schooler, J.W. (2009). Lost in the sauce. The effects of alcohol on mind wandering. *Psychological Science*, *20*, 747–752. doi: 10.1111/j.1467-9280.2009.02351.x

Sayette, M.A., Schooler, J.W., and Reichle, E.D. (2010). Out for a smoke. The impact of cigarette craving on zoning out during reading. *Psychological Science*, *21*, 26–30. doi: 10.1177/0956797609354059

Scherer, K.R. (2009). Emotions are emergent processes: They require a dynamic computational architecture. *Philosophical Transactions of the Royal Society B. 364*, 3459–3474. doi: 10.1098/rstb.2009.0141

Scherer, K.R., and Meuleman, B. (2013). Human motion experiences can be predicted on theoretical grounds: Evidence from verbal labeling. *PLoS One, 8*, e58166. doi: 10.1371/journal.pone.0058166

Schooler, J.W. (2002). Re-representing consciousness: Dissociations between experience and meta-consciousness. *Trends in Cognitive Sciences*, *8*, 339–344. doi: 10.1016/S1364-6613(02)01949–6

Schooler, J.W., Ariely, D., and Loewenstein, G. (2003). The pursuit and assessment of happiness can be self-defeating, In I. Brocas and J.D. Carrillo (Eds.), *The psychology of economic decisions, volume I, rationality and well-being* (pp. 41–70). New York: Oxford University Press.

Senden, M., Reuter, N., van den Heuvel, M.P., Goebel, R., Deco, G., and Gilson, M., (2018). Task-related effective connectivity reveals that cortical rich club gates cortex-wide communication. *Human Brain Mapping, 39*, 1246–1262. doi: 10.1002/hbm.23913

Shanahan, M. (2005, April). Consciousness, emotion and imagination. A brain-inspired architecture for cognitive robots. In K. Dautenhahn (Chair), *Next generation approaches to machine consciousness. Imagination, development, intersubjectivity and embodiment*. Symposium conducted at AISB 2005, Hatfield, United Kingdom.

Shanahan, M. (2006). A cognitive architecture that combines internal simulation with a global workspace. *Consciousness and Cognition, 15,* 433–449. doi: 10.1016/j.concog.2005.11.005

Shapira O., Gundar–Goshen, A., and Dar, R. (2013). An ironic effect of monitoring closeness. *Cognition and Emotion*, *27*, 1495–1503. doi: 10.1080/02699931.2013.794771

Sio, U.N., and Ormerod, T.C. (2009). Does incubation enhance problem solving? A meta-analytic review. *Psychological Bulletin*, *135*, 94–120. doi: 10.1037/a0014212

Sklar, A.Y., Nevy, N., Goldstein, A., Mandel, R., Maril, A., and Hassin, R.R. (2012). Reading and doing arithmetic nonconsciously. *Proceedings of the National Academy of Sciences, USA, 109*, 19614–19619. doi: 10.1073/pnas.1211645109

Smallwood, J., McSpadden, M., and Schooler, J.W. (2007). The lights are on but no one's home: Meta-awareness and the decoupling of attention when the mind wanders. *Psychonomic Bulletin & Review*, *14*, 527–533. doi: 10.3758/BF03194102

Smallwood, J., Ruby, J.W., and Singer, T. (2013). Letting go of the present: Mind-wandering is associated with reduced delay discounting. *Consciousness and Cognition*, *22*, 1–7. doi: 10.1016/j.concog.2012.10.007

Smallwood, J., and Schooler, J.W. (2006). The restless mind. *Psychological Bulletin*, *132*, 946–958. doi: 10.1037/0033-2909.132.6.946

Smith, S.M., Miller, K.L., Moeller, S., Xu, J., Auerbach, E.J., Woolrich, M.W., Beckman, C.F., Jenkinson, M., Andersson, J., Glasser, M.F., Van Essen, D.C., Feinberg, D.A., Yacoub, E.S., and Ugurbil, K. (2012). Temporally-independent functional modes of spontaneous brain activity. *Proceedings of the National Academy of Sciences, USA*. *109*, 3131–3136. doi: 10.1073/pnas.1121329109

Sohn, J., Kim, H., Sohn, S., Seok, J., Choi, D., and Watanuki, S. (2015). Effect of emotional arousal on inter-temporal decision-making: An fMRI study. *Journal of Physiological Anthropology*, *34*, 8. doi: 10.1186/s40101-015-0047-5

Son, L.K., and Schwartz, B.L. (2002). The relation between metacognitive monitoring and control. In T.J. Perfect and B.L. Schwartz (Eds), *Applied metacognition* (pp. 15–38). Cambridge: Cambridge University Press. doi: 10.1017/CBO9780511489976.003

Song, X., and Tang, W. (2008). An extended theory of global workspace of consciousness. *Progress in Natural Science*, *18*, 789–793. doi: 10.1016/j.pnsc.2008.02.003

Song, X., and Wang, X. (2012). Mind wandering in Chinese daily lives — an experience sampling study. *PLoS One*, *7*, e44423. doi: 10.1371/journal.pone.0044423

Stanovich, K.E. (2009). Distinguishing the reflective, algorithmic and autonomous minds: Is it time for a tri-process theory? In J. Evans and K. Frankish (Eds.), *In two minds: Dual processes and beyond* (pp. 55–88). New York: Oxford University Press. doi: *10.1093/acprof*: *oso/9780199230167.001.0001*

Staresina, B.P., and Davachi, L. (2009). Mind the gap: Binding experiences across space and time in the human hippocampus. *Neuron*, *63*, 267–276. doi: 10.1016/j.neuron.2009.06.024

Stark, R., Schienle, A., Walter, B., Kirsch, P., Sammer, G., Ott, U., Blecker, C., and Vaitl, D. (2003). Hemodynamic responses to fear and disgust-inducing pictures: An fMRI study. *International Journal of Psychophysiology*, *50*, 225–234. doi: 10.1016/S0167-8760(03)00169–7

Stawarczyk, D., Majerus, S., Maj, M., Van der Linden, M., and Argembeau, A. (2011). Mind-wandering: Phenomenology and function as assessed with a novel experience sampling method. *Acta Psychologica*, *136*, 370–381. doi: 10.1016/j.actpsy.2011.01.002

Steriade, M., McCormick, D.A., and Sejnowski, T.J. (1993). Thalamocortical oscillations in the sleeping and aroused brain. *Science*, *26*, 679–685. doi: 10.1126/science.8235588

Tanner, A., Voon, D., Hasking, P., and Martin, G. (2013). Underlying structure of ruminative thinking: Factor analysis of the ruminative thought style questionnaire. *Cognitive Therapy and Research, 37,* 633–646. doi: 10.1007/s10608-012-9492-1

Thomsen, D. K. (2006). The association between rumination and negative affect: A review. *Cognition and Emotion, 20*, 1216–1235. doi: 10.1080/02699930500473533

Trampe, D., Quoidbach, J., and Taquet, M. (2015). Emotions in everyday life. *PLoS One*, *10*, e0145450. doi: 10.1371/journal.pone.0145450

Tusche, A., Smallwood, J., Bernhardt, B.C., and Singer, T. (2014). Classifying the wandering mind: Revealing the affective content of thoughts during task-free rest periods. *NeuroImage*, *97*, 107–116. doi: 10.1016/j.neuroimage.2014.03.076

van den Heuvel, M.P., and Sporns, O. (2013). Network hubs in the human brain. *Trends in Cognitive Sciences*, *17*, 683–696. doi: 10.1016/j.tics.2013.09.012

Vanhaudenhuyse, A., Demertzi, A., Schabus, M., Noirhomme, Q., Bredart, S., Boly, M., Phillips, C., Soddu, A., Luxen, A., Moonen, G., and Laureys, S. (2010). Two distinct neuronal networks mediate the awareness of environment and of self. *Journal of Cognitive Neuroscience*, *23*, 570–578. doi: 10.1162/jocn.2010.21488

Vatansever, D., Manktelow, A.E., Sahakian, B.J., Menon, D.K., and Stamatakis, E.A. (2016). Cognitive flexibility: A default network and basal ganglia connectivity perspective. *Brain Connectivity*, *6*, 201–207. doi: 10.1089/brain.2015.0388

Vértes, P,E., Rittman, T, Whitaker, K.J., Romero–Garcia, R., Váša, F., Kitzbichler, M.G., Wagstyl, K., Fonagy, P., Dolan, R.J., Jones, P.B., Goodyer, I.M., the NSPN Consortium, and Bullmore, E.T. (2016). Gene transcription profiles associated with inter-modular hubs and connection distance in human functional magnetic resonance imaging networks. *Philosophical Transactions B*, *37,* 20150362. doi: 10.1098/rstb.2015.0362

Wager, T.D., Kang, J., Johnson, T.D., Nichols, T.E., Satpute, A.B., and Barrett, L.F. (2015). A Bayesian model of category-specific emotional brain responses. *PLoS Computational Biology*, *11,* e1004066. doi: 10.1371/journal.pcbi.1004066

Wang, J., Wang, L., Zang, Y, Yang, H., Tang, H., Gong, Q., Chen, Z., Zhu, C., and He, Y. (2009). Parcellation-dependent small-world brain functional networks: A resting-state fMRI study. *Human Brain Mapping, 30*, 1511–1523. doi: 10.1002/hbm.20623

Wang, K., Yu, C., Xu, L., Qin, W., Li, K., Xu, L., and Jiang, T. (2009). Offline memory reprocessing: Involvement of the brain's default network in spontaneous thought processes. *PLoS One*, *4,* e4867. doi: 10.1371/journal.pone.0004867

Winkielman, P., and Berridge, K.C. (2004). Unconscious emotion. *Current Directions in Psychological Science*, *13*, 120–123. doi: 10.1111/j.0963-7214.2004.00288.x

Whitmer, A.J., and Banich, M.T. (2007). Inhibition versus switching deficits in different forms of rumination. *Psychological Science*, *18*, 546–553. doi.org/10.1111/j.1467-9280.2007.01936.x

Yantis, S. (2008). The neural basis of selective attention: Cortical sources and targets of attentional modulation. *Current Directions in Psychological Sciences, 17*, 86–90. doi: 10.1111/j.1467-8721.2008.00554.x

Yesavage, J.A., Rose, T.L., and Bower, G.H. (1983). Interactive imagery and affective judgements improve face-name learning in the elderly. *Journal of Gerontology*, *38*, 197–203. doi: 10.1093/geronj/38.2.197

Yoon, K, L., Hong, S.W., Joormann, J., and Kang P. (2009). Perception of facial expressions of emotion during binocular rivalry. *Emotion*, *9*, 172–182. doi: 10.1037/a0014714

Zeelenberg, M, Nelissen, R.M.A, Breugelmans, S.M., and Pieters, R. (2008). On emotion specificity in decision making: Why feeling is for doing. *Judgment and Decision Making, 3*, 18–27.

Zeki, S., Romaya, J.P., Benincasa, D.M.T., and Atiyah, M.F. (2014). The experience of mathematical beauty and its neural correlates. *Frontiers in Human Neuroscience, 8,* 68. doi: 10.3389/fnhum.2014.00068

Zelaso, P.D. (2015). Executive function: Reflection, iterative reprocessing, complexity and the developing brain. *Developmental Review*, *38*, 55–68. doi: 10.1016/j.dr.2015.07.001

Zelensky, J.M., and Larsen, R.J. (2000). The distribution of basic emotions in everyday life: A state and trait perspective from experience sampling data. *Journal of Research in Personality*, *34*, 178–197. doi: 10.1006/jrpe.1999.2275

Zylberberg, A. Dehaene, S. Roelfsema, P.R., and Sigman, M. (2011). The human Turing machine: A neural framework for mental programs. *Trends in Cognitive Sciences*, *15*, 293–300. doi: 10.1016/j.tics.2011.05.007

Zylberberg, A., Slezak, D.F., Roelfsema, P.R., Dehaene, S., and Sigman, M. (2010). The brain's router: A cortical network model of serial processing in the primate brain. *PLoS Computational Biology, 6,* e1000765. doi: 10.1371/journal.pcbi.1000765