Trends in Cognitive Sciences

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Opinion

Overarching States of Mind

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We all have our varying mental emphases, inclinations, and biases. These individual dispositions are dynamic in that they can change over time and context. We propose that these changing states of mind (SoMs) are holistic in that they exert all-encompassing and coordinated effects simultaneously on our perception, attention, thought, affect, and behavior. Given the breadth of their reach, understanding how SoMs operate is essential. We provide evidence and a framework for the concept of SoM, and we propose a unifying principle for the underlying cortical mechanism whereby SoM is determined by the balance between top-down (TD) and bottom-up (BU) processing. This novel global account gives rise to unique hypotheses and opens new horizons for understanding the human mind.

Highlights

An individual can demonstrate striking variability in their cognitive, affective, and behavioral inclinations in different contexts.

To account for these dynamics, we offer evidence and a framework for a global concept, that we term SoM, whereby all the diverse dimensions of functioning, from perception and attention to thought, affect, and behavior, are clustered together and change in tandem.

We further propose a unifying principle for the cortical mechanism underlying the overarching SoMs.

This unifying principle postulates that SoM is determined by the balance between TD and BU cortical processing.

We show how this novel proposal can advance theories and approaches in psychology, neuroscience, and psychiatry.

Introducing States of Mind

SoM is not merely a figure of speech. The human mind can have different dispositions and tendencies, which together comprise our current state. The notion that the mind can operate in varying ways has been recognized by several psychological fields and has been conceptualized from their corresponding viewpoints. In clinical psychology, the concept of ‘multiple self-states’ points to different versions of the self that arise in different **relational contexts** (see Glossary) [1]. In cognitive psychology, ‘mindset’ describes a configuration of processing resources available for a subsequent task [2]. For example, a mindset elicited by engaging in a task with clear rules drastically impaired subsequent functioning in a task that requires creative thinking [3]. In social psychology, according to the construal level theory (CLT), inducing an abstract versus a concrete mindset modulates subjectively estimated psychological distance across various dimensions, such as estimated temporal, spatial, or social distances [4]. In educational psychology, ‘mindsets’ were conceptualized as the beliefs one holds regarding one's personal abilities, which can hamper or foster performance [5,6].

These different accounts acknowledge that the mind is a dynamic construct that can change according to circumstances. However, we do not have any comprehensive account to explain what constitutes these SoMs, how the dynamics of different dimensions (cognitive, behavioral and emotional) relate to one another, what evokes their transition, the extent of their influence, and their underlying cortical mechanism. Given that different states can change our subjective experience of the environment, being able to explain how they operate is essential for understanding how the mind works.

We propose an overarching framework to explain the global construct of SoM (Figure 1, Key Figure). Within this framework, SoM captures a qualitatively more sweeping effect of state over our mental life, encompassing cognition (including perception, attention, and thought), behavior (including openness to experience), and affect, which together we take as the principal dimensions of SoM. These dimensions are principal in that other mental dimensions (e.g., motivation, absorption) can be derived from their combination. They were chosen following our accumulated observations in the laboratory and from the literature (if new dimensions of our mental life are subsequently proposed that are affected by the overarching SoM, but cannot be constructed from the principal dimensions we describe, this will be a welcome addition to the evolution of this

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framework). Although seemingly unrelated, we propose that these dimensions are clamped together by the SoM, and that they change along a continuum ranging from narrow to broad.

In support of our proposal, we first show that each principal dimension of SoM is state-dependent, and then review evidence showing that these dimensions are interdependent. That is, being at one end of one dimension (e.g., broad thinking) also entails broad perception, global attention, exploratory behavior, and positive mood. Conversely, being at the opposite end of one dimension (e.g., narrow thinking) also entails narrowed perception, local attention, exploitatory behavior, and negative mood. We refer to these two extremes as broad and narrow SoM, respectively, representing the two endpoints of a continuous SoM. One is rarely at either extreme of this SoM continuum. We then propose a neural mechanism underlying SoM, show how it pertains to each of the SoM principal dimensions, and outline specific predictions that stem from this framework.

The Principal Dimensions of SoM are State-Dependent

Scope of Perception: Incoming Sensory Information versus Predictions

Perception of the physical world is a principal dimension affected by SoM. It is shaped by incoming sensory input that propagates BU along a cortical hierarchy of increasing complexity. However, perception is equally shaped by our past experiences, memory, and predictions in a TD manner. TD influences on perception are demonstrated in multiple sensory modalities, including tactile [7], auditory [8], and visual [9,10]. Taken together, perception is a continuous dimension ranging from unconstrained, broad perception, that relies on incoming BU information, to narrow perception that relies on specific TD predictive guidance.

Scope of Attention: Local versus Global

Scope of attention relates to the breadth and resolution with which we consume our environment. In this SoM dimension, we can selectively attend either the global (broad) properties (the ‘forest’) or the local (narrow) properties (‘trees’) of the world around us. In natural settings, local and global features are combined to guide object detection and recognition [11]. However, the degree to which we rely on local versus global information is subject to state-dependent changes. For example, ‘Navon-type’ stimuli are frequently employed to demonstrate the shift between local and global attention. In this paradigm, a large global shape (such as the letter ‘T’) is composed of many smaller local shapes (such as the letter ‘s’). By asking participants to focus either on the global shape or on its component elements, the attentional processing style can be manipulated [12]. Without any manipulation, a 'global precedence effect' is usually found, referring to faster detection of the global rather than the local pattern. However, prior predictions can counteract this global precedence, leading to narrowed, local attentional scope [13].

Scope of Thought: Narrow versus Broad Thinking Style

Scope of thought also ranges from narrow to broad. Narrowed thinking is more confined in its scope, occupying selective content or following defined rules, whereas broad thinking is unlimited in scope and is not governed by any constraining rule other than coherence. For example, associative thinking is one dimension along which one can evaluate the scope of thought. At the narrow end, a person will tend to activate close semantic associations to a precipitating stimulus (e.g., for 'bed', the associations may be 'blanket', 'pillow', 'sleep', all narrowly related to 'bed'). Ruminative thinking is an example of an extremely narrow thinking style in which the individual repetitively reminiscences about a specific event, fixates on its surrounding topics, and exhibits difficulty disengaging from it even when this ruminative process is disadvantageous. At the broad end of this spectrum, a person will invoke remote associations to a stimulus (e.g., for 'bed', the associations may be 'book', 'tree', 'stars'). Her thoughts can maneuver from one idea to another, advancing far and fast. At the utmost end of broad thinking, ideas are presented

Glossary

Default mode network (DMN): a consistent pattern of brain activity that is often observed when the participant is not engaged in any external task. The DMN includes regions of the medial prefrontal cortex, medial temporal lobe, and posterior cingulate cortex, and is hypothesized to be involved in different mental functions such as simulations and thinking about the self and about others.
Neurofeedback: a procedure in which the individual receives a signal reflecting his current brain activity and can learn, through feedback, to manipulate his brain activity according to a predefined rule.
Relational context: the interpersonal situation. In clinical psychology, early interpersonal relationships of the child with his primary caregivers are often believed to shape his internalized representations, which later influence the way he responds to different interpersonal contexts in his life.
Resting state: an unconstrained state of brain activation in which no explicit task is being performed by the participant.
Transcranial magnetic stimulation (TMS): a non-invasive brain stimulation technique in which a coil is placed on the scalp and creates a magnetic field that can influence the underlying neural activation in a localized manner.

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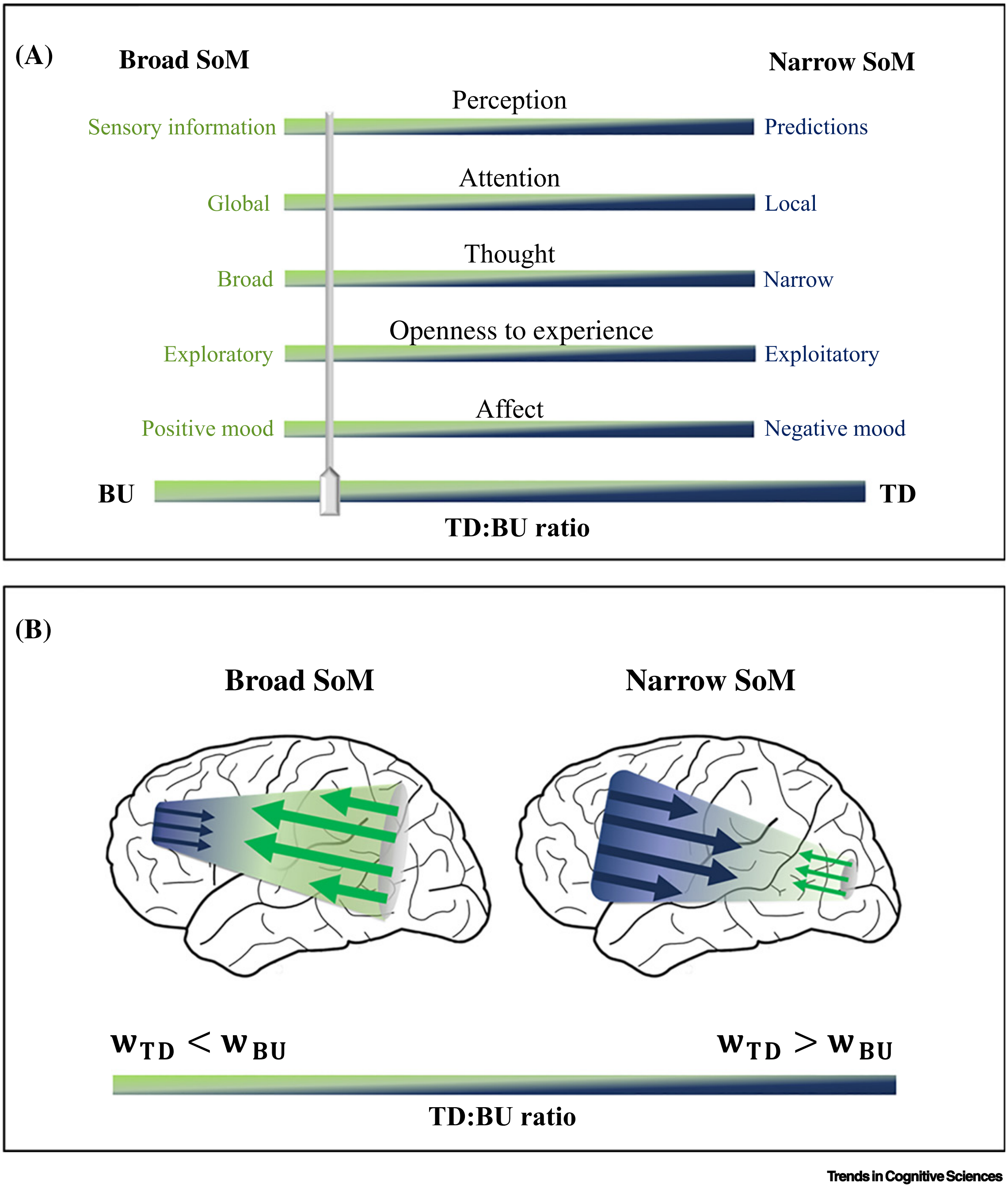
Key Figure

Dimensions of State of Mind (SoM) and Their Proposed Neural Mechanism



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Box 1. SoM versus Personality

Both SoM and personality traits account for the influence of prior dispositions on attitudes, cognition, and performance. However, the SoM framework suggests that this disposition is dynamic and transitory. As opposed to predicting behavior from a fixed set of personality traits, the SoM framework takes into consideration intraindividual variability. For example, the account of personality traits would predict that a person rated high on 'openness to experience' on the big five scale is more likely to be exploratory than exploitatory. Under the SoM framework, however, the same person is likely to respond to novel events in a more open and exploratory way when happy compared to times when he is feeling depressed.

Although SoMs are more transitory than personality traits, they are equally influential. To acknowledge the possible impact of SoM, one can observe the clinical condition of dissociative identity disorder (DID; previously referred to as multiple personality disorder), that is diagnosed when an individual exhibits the coexistence of two or more distinct 'personality states'. Each of these distinct identities has its own unique traits, including a different set of affective states, behavioral tendencies, cognitive abilities, and perception [84]. This condition, although rare and somewhat controversial, demonstrates the multiple and divergent SoMs that our brain can sustain. Neurotypical individuals also possess different modes of processing, even if these are less distinct from one another and there is a preserved sense of continuity when roaming between them. At times we can be full of confidence, act proudly and without inhibitions, whereas at other times we can feel insecure, unsuccessful, and inhibited. Our personality makeup can come in different shapes and forms, depending on our SoM.

Corresponding to this idea, efforts to find a correlation between functional brain activity and individual traits were not successful when applied during **resting state**. However, prediction of individual traits based on the neural circuitry was much improved when applied during engagement in tasks such as emotion processing or a working memory task [85,86]. It is possible that the engagement in a task-induced state that elicit the traits of interest is necessary to find the desired brain–behavior correlation. In a similar manner, some of the abnormal neural underpinnings and cognitive impairments found in clinical populations can be seen only during provocation of the symptomatic state [87,88]. These findings imply that the correlation between brain activity and behavior primarily relies on current SoM.

with extremely loose logical connection between them, a thought disorder termed 'loose associations'. Although loose associations are often described as a characteristic feature of schizophrenia [14], and ruminations are often described as a typical feature in depression [15], a healthy thinking style continuously changes across this continuum of associativity.

Openness to Experience: Exploitation versus Exploration

The extent to which we explore our environment for new information or alternatively exploit what is already known to us forms the SoM dimension of openness to experience (hereafter, openness). Although narrowing our openness and exploiting the familiar enables us to rely on existing knowledge and avoid danger, broadening our openness and exploring enables us to learn and make new discoveries. Traditionally, openness was considered to be a permanent personality trait and part of the 'big five' model of personality structure [16]. Individuals who score high on this personality trait are described as creative, curious, and unconventional [17]. Nevertheless, a core argument in our framework is that SoMs are dynamic states that are flexible within the same individual (a comparison between personality and SoM is given in Box 1). Accordingly, we consider openness as a variable state along the exploration–exploitation spectrum. Indeed, although high openness as personality trait has been found to correlate with indicators of creativity such as divergent thinking [18,19], other accounts have proposed that such correlation is dependent upon situational factors such as the existence of positive feedback and undefined instructions [20]. Hence, whether we venture to explore or resort to exploitation depends on the context.

Figure 1. (A) Illustration of SoM and its multiple dimensions of influence. The different dimensions are interconnected to one another and they change in tandem. A broad SoM (left) consists of perception that relies mostly on sensory input, global attention, broad thinking, exploratory disposition, and a positive mood – all involving increased bottom-up (BU) processing. A narrow SoM (right) consists of perception that is heavily influenced by predictions, local attention, narrow thinking, exploitatory disposition, and a negative mood – all involving increased top-down (TD) processing. The TD:BU ratio (green–blue axis) is the proposed mechanism for dictating the SoM, and affects where all dimensions are on the spectrum. (B) A schematic description of the proposed neuronal mechanism, whereby the ratio between TD processing and BU processing determines how broad or narrow the SoM is. In broad SoM, the weights of the TD processing (W_{TD}) are smaller, and thus TD influences are less dominant, whereas in narrow SoM less weight is given to the BU input.

Affect: Negative versus Positive Mood

We know that mood fluctuates across time. We can easily observe the subjective pleasantness accompanying a happy mood and the unpleasantness experienced during a negative mood. Both ends of the mood spectrum embody significant mood disorders: major depression at the negative end and mania at the positive end. Nonetheless, everyday experience summons events that often lead the mood of an individual to fluctuate between the positive and the negative. Although it may not be immediately obvious how negative and positive mood map onto the 'broad' versus 'narrow' distinction, as discussed in the next section, affect covaries with the other principal SoM components, such that being in a negative mood is related to a narrow SoM, and being in a positive mood is related to a broad SoM.

In sum, each of the five dimensions varies along a continuum, from broad to narrow. In the next section we briefly review evidence that these dimensions vary together.

The Principal Dimensions of SoM Are Interdependent

The dimensions comprising our overarching SoM range between broad and narrow depending on state. A wealth of research indicates that these principal dimensions are also dependent on each other and that they change together (Table 1). According to these past findings, perception guided by predictions goes hand in hand with local attention, narrow thought, exploitatory disposition, and negative affect (narrow SoM), whereas perception relying on incoming sensory information goes with global attention, broad thought, exploratory disposition, and positive affect (broad SoM).

Table 1 summarizes numerous indications for these interdependencies, but one detailed example can further illustrate the way these dimensions are inherently synchronized to change in tandem. Perception can become highly reliant on TD predictive processing under conditions of stress and catastrophizing, narrowed, cognitions. Such narrowed perception can be demonstrated in biased perception of facial expressions after induction of a negative mood [21], or by the biased perception of a feared stimulus in individuals suffering from specific phobias [22]. Psychotherapy can decrease such perceptual distortions by incorporating methods such as producing alternative thoughts (inducing broader thinking), exposure to the feared situations, and relaxation [23]. Physical exercise can also reduce biased perception [24], together suggesting that SoM modifications such as broadening thought, improving mood, and inducing more exploratory behavior can decrease TD influences on perception. Conditions of stress and anxiety not only lead to narrowed perception but also cause individuals to execute preplanned actions without exploring for new alternative ideas or behaviors. This exploitatory tendency, termed 'threat-rigidity effect', also leads to the generation of dominant, more frequent words in a verbal test (reflecting narrowed thought), even when this hampers performance [25]. This effect was suggested to result from failure to notice relevant peripheral information owing to a narrowed attentional scope, as well as over-reliance on prior (TD) expectations [26,27].

The interconnections between the SoM dimensions could be mediated by neurotransmitters. For instance, stressors stimulate the release of norepinephrine (NE), leading to more rigid and stereotypic responses under these conditions [28]. High levels of NE were found to induce goal-directed behavior by narrowing attentional focus [29]. By contrast, low levels of NE were proposed to enable activation of broad associative thinking by lowering the signal-to-noise ratio in the cortex, leading to increased intrinsic associative activity [30].

Future studies could directly test the interconnectedness proposed here between the principal SoM dimensions using existing behavioral paradigms. These include modulation of perceptual scope [31], attentional scope [32], thinking scope [3,33,34], affect [35], and more recently the

Table 1. Principal SoM Dimensions Are Interdependent

Principal SoM dimension	Interdependence with other principal SoM dimensions
Perception	Stress and catastrophizing cognitions bias perception towards TD guidance. For example, biased perception of a feared stimulus was shown in individuals suffering from specific phobias [22], overestimation of body size was shown in individuals suffering from eating disorders [89], and biased perception of facial expressions was found after induction of a negative mood [21].
	Perceptual distortions can be rectified by modifying maladaptive thoughts, exposure to the feared situations, and relaxation [23].
	Inducing broad thinking can improve cross-sensory assimilation in perception [90].
	Global attention can improve taste recognition [91].
Attention	Predictive diagnostic information can bias attention from global to local precedence [13].
	Familiar contexts in object display sustain local attention by enabling attention to be directed to regions of interest of the percept [81].
	Shifting attention to local processing impairs face recognition, whereas eliciting global attention enhances the accuracy of face recognition [82].
	Positive mood promotes greater focus on global properties, whereas negative mood promotes focus on details [83,92].
	Induction of positive mood broadens attentional scope for external stimuli, as well as for the internal conceptual space, by increasing access to remote semantic associations [93].
	Inducing a broad thinking style using divergent thinking tasks leads to global attention [94].
	Local attention elicits an exploitatory disposition, whereas global attention entails more exploration [95].
Thought	Approach orientation, which points to increased exploration tendency, promotes broad associative thought. Avoidance orientation, which relates to exploitatory behavior, promotes narrowed thought [96].
	Muscular actions associated with approaching behavior, compared to avoidant behavior, promote broad associative thought [33].
	Broad thinking leads to better mood [34,53], and being in a positive mood induces broad associative thinking [30–32].
	High cognitive load, which is akin to exploitation, limits the breadth of associative thought, resulting in the generation of mundane associations at the expense of remote associations that characterize creative thinking [97].
	Problem-solving tasks that are classified as 'intuitive' benefit from holistic approach and global attention, whereas 'analytic' tasks benefit from a deliberative, detail-oriented, and systematic problem-solving approach [98,99].
	Personal agency ranges between two extremes: low-level agents, who are more likely to think and describe their behavior at the level of details and mechanistic components, and high-level agents, who view their actions in terms of its higher significance, such as causal effects and social meanings. People with high-level agency (corresponding to broad thinking) feel more comfortable in undertaking a wider variety set of actions. Correspondingly, low-level agency relates to greater sensitivity to contextual cues, higher predictive power, and improved performance in complex tasks or unfamiliar environments. It is further suggested that stressful life events promote low-level agency [44].
	Sense of threat leads to a 'threat-rigidity effect' that biases behavior toward exploitative, habitual, and restricted performance [25]. This effect involves narrow attentional scope and over-reliance on TD expectations [26,27].
Openness to experience	Positive mood increases the likelihood of manifesting an exploratory strategy [100].
	The broaden-and-build theory suggests that positive affect prompts individuals to discard automatic behaviors and pursue novel and unscripted paths of thought and action. On the other hand, negative mood functions to narrow a person's momentary thought–action repertoire by producing habitual actions that are crucial for survival [101].
	High norepinephrine (NE) levels may link exploitation with narrow thought, stress, and local attention. Stressors stimulate NE release, leading to rigid and stereotypic

(continued on next page)

Table 1. (continued)

Principal SoM dimension	Interdependence with other principal SoM dimensions
	responses [28], and high NE levels induce goal-directed behavior by narrowing attentional focus [29]. By contrast, low NE levels were proposed to enable activation of broad associative thinking by lowering signal-to-noise ratio in the cortex, leading to increased intrinsic associative activity [30].
	Cost and utility are situational factors that have been suggested to influence exploration–exploitation tendencies. When prior events are predictive of high utility, exploitation is enhanced. When predicted utility is low, exploration of new opportunities emerges [102].
Affect	Inducing divergent thinking promotes positive mood, whereas inducing convergent thinking promotes negative mood [33].
	Inducing a thinking pattern that involves associative progression leads to better mood compared to inducing a thinking pattern that stagnates on a single topic [34].
	Positive mood leads to more flexible thinking, reflected in the activation of unusual associations [103,104], facilitates switching between cognitive sets [105], and reduces perseveration [106]. Increased dopamine levels in the anterior cingulate cortex under positive affect were suggested to mediate this connection [107].
	Positive mood broadens attentional scope, whereas negative mood is associated with more focused and selective attention [108].

indirect modulation of openness [36]. The SoM framework predicts that modulation of one of these dimensions (spontaneously or by experimental induction) will result in a corresponding change in the other SoM dimensions. Finally, although the modulation of the different scopes appears to occur on a fast timescale, the specific timescales for each dimension should be further investigated and might reveal a gradual synchrony between dimensions across time (e.g., a change in scope of thought might take place somewhat faster than a change in mood).

The Neural Mechanism of SoM

We have shown support for our proposal that the principal dimensions of SoM – perception, attention, thought, openness, and affect – are interdependent and change in tandem. The SoM orchestrates the disposition across all these dimensions, aligning them together like a web cast over a host of mental processes. What might explain these global covariations? We propose that a single mechanism underlies this synchronous dynamic, which gives rise to the all-encompassing nature of SoM: state of mind is determined by the balance between TD and BU cortical processing. The different SoM dimensions are all connected and determined by the same 'steering' mechanism that is the TD:BU ratio.

Cognitive neuroscience research in a wide range of domains has provided the foundations for our proposal about the link between BU and TD processes and SoM. TD processing implies reliance on predictions that are derived from past experiences, memory, and context [37,38]. BU processing, on the other hand, relies on the direct input from our senses without guidance (and possible distortion) from higher areas in the cortical hierarchies [39]. We propose that our brain combines TD and BU signals to varying degrees, depending on state. The TD:BU ratio is a single mechanism that operates simultaneously on multiple continuous dimensions (Figure 1A), rather than reflecting a dichotomous dual-process typology ([40] for a critical discussion of dual-process theories).

Specifically, the account proposed here is that the TD:BU ratio determines that the scope of each SoM dimension is broader or narrower by using a combination of inhibition and weighting that controls the respective contributions of TD and BU processes (Figure 1B). In narrow SoM, increased inhibition constricts the breadth of activation, both for 'reception' (as in perception and attention) and in 'transmission' (as in thoughts and affect), and weights that give an advantage to TD processing are applied. Similarly, the complementary weights and (reduced) inhibitions are deployed for a broad SoM, with an open scope and weights that give a higher emphasis to BU processing, increasing exploration, curiosity, and creativity, a broader scope for thought, attention, and perception, and a more positive mood. In fact, the TD:BU ratio not only determines SoM, the TD:BU ratio is the SoM. All points along the continuum of SoM dimensions are derived from the TD:BU ratio (Figure 1).

The contribution of the TD:BU ratio to SoM can be measured empirically. TD influences have been discussed broadly and widely for decades, and putative brain areas for the generation of TD influences in perception, attention, thought, openness to exploration versus exploitation, and mood have been mapped to various degrees. Similarly, the origin of BU signals is clear for at least some of these (e.g., perception). Although the methods used to measure the TD:BU ratio are not trivial and still need to be refined and standardized, we provide here several proposals for pursuing this aim. We focus on a neuroimaging examination of specific regions of interest (ROIs) following the induction of broad SoM, narrow SoM, and anywhere in between, to test the hypothesis that TD:BU ratio determines SoM.

Future research will help to test and delineate the characteristics of this mechanism, and more details will naturally emerge about the origin and the modulation of TD and BU signals as a function of SoM. A variety of factors likely contribute to determining the TD:BU ratio. Beyond the relative levels of activation in relevant regions, the balance between excitation and inhibition may play a role. Furthermore, there is no question that neuromodulators such as the noradrenergic, serotonergic, dopaminergic, and cholinergic systems, which are involved in detecting situational information such as reward, certainty, emotion, novelty and social cues, are also involved.

In support of our proposal, we now survey each SoM dimension in turn, and show how it is determined by the TD:BU ratio.

SoM Dimensions Are Determined by the TD:BU Ratio

Scope of Perception

BU and TD processes interact in forming coherent perception. Whereas BU processes refer mainly to the saliency of the sensory input, TD information relies on prior experience, and emanates mainly from frontal neural activity [41]. Perception that is highly influenced by predictions relies on TD activation that facilitates processing of relevant sensory information and at the same time inhibits processing of irrelevant information. For instance, prior expectations suppress processing of incongruent BU sensory signals in the primary visual area while enhancing signals conveying congruent information [42].

Without prior expectations, perception relies on sensory signals derived by the external stimuli in a BU manner. For example, reduction of contextual information of a scene by scrambling leads to greater reliance on BU saliency-based processing [31]. Meditation training was also reported to reduce habitual patterns of perceptual activation, suggesting induction of BU processing [43,44]. Recent studies suggest that perception is shaped by the balance between TD and BU cues [45,46]. Thus, the way we perceive the world can change in scope from high predictive guidance relying on increased TD signals to high reliance on sensory input through increased BU processing.

In visual object recognition, TD signals emanating from the orbitofrontal cortex (OFC) have been linked to successful object recognition, as reflected by fMRI and magnetencephalography (MEG) signals [47]. The SoM framework predicts that, in paradigms of object recognition, the ratio between level of activity incorporated from the OFC relative to sensory visual areas will be lower under broad SoM than under narrow SoM (which could be tested with fMRI), and that the temporal precedence of the OFC activation compared to activation of sensory visual areas (which could be tested with MEG) will be diminished.

Scope of Attention

The TD:BU ratio also coincides with the amount of attentional resources that are dedicated to local versus global processing. The greater the ratio, the more localized is our attention.

TD facilitation of local attention can be demonstrated via 'category learning' – characterized by selective attention to the most diagnostic features of the item in the to-be-learned categories. For instance, when learning to distinguish squirrels from chipmunks, TD information guides attention to features that discriminate between the groups, such as the existence of stripes, and not to non-diagnostic features such as having a tail [48]. This TD guidance of local attention was demonstrated by optimizing eye fixation patterns to task-relevant features [49], and involves lateral prefrontal regions [50]. At the other end of the attentional scope, increased weight of BU processing (i.e., decreasing the TD:BU ratio) leads to more global attention. As an illustration of this point, mindfulness meditators practicing 'distributed attention' are better at detecting unexpected BU stimuli [51], reflecting the way global attention is associated with increased BU processing of the environment (in the context of meditation, one must keep in mind that there are numerous approaches and these are sometimes radically different in practice. Some methods aim at diffusing attention and making it more global, whereas others involve highly focused attention on a single object, such as breathing. We argue that many of these different approaches strive to and result in a similar outcome of diminishing TD influences in perception).

TD influence on attention allocation has been widely investigated, thus allowing delineation of neural ROIs for testing the TD:BU ratio. For example, studies on covert attention allocation show that TD signals enhance the processing of attended stimuli by biasing the sensory cortex before stimulus onset [52]. The degree to which successful attention allocation has been achieved can be indexed by alpha power desynchronization in the hemisphere contralateral to the attendant hemifield [52]. This so-called alpha lateralization index can be measured on a trial-by-trial basis, thus enabling investigation of the hypothesis that SoM alterations will influence the scope of attention. The SoM framework would predict that induction of narrow SoM will lead to a higher TD:BU ratio, indexed by higher alpha lateralization, whereas induction of broad SoM will lead to a lower TD:BU ratio, indexed by lower alpha lateralization.

Scope of Thought

According to our framework, broad thinking is linked to a low TD:BU ratio, enabling the thought process to progress in multiple directions under reduced TD restrictive guidance and inhibition. On the other hand, narrowed thinking relies on a high TD:BU ratio because intensified TD signals prevent distraction by competing thoughts. It has been proposed [53] that such TD activation manifests as hyperinhibition from medial prefrontal cortex (mPFC) to medial temporal lobe (MTL), constricting the breadth of associative activation and thereby eliciting a narrower and ruminative pattern of thinking (Figure I in Box 3). This proposal was supported by studies showing increased activity in the mPFC during ruminative thinking [54,55] and during self-referential processing associated with ruminations [56,57]. Correspondingly, individuals suffering from major depression, that is often characterized by a ruminative style of thought, were also found to exhibit abnormal hyperactivation of mPFC [58,59]. On the other hand, individuals suffering from schizophrenia, who often exhibit a thought pattern of loose associations and reduced inhibition, demonstrate general hypofrontality both at rest and during a neuropsychological task [60,61], as well as decreased connectivity in the white matter tracts connecting temporal and prefrontal regions [62] (a more elaborate discussion of clinical disorders and SoM is given in Box 2).

Another demonstration of the way TD:BU weights interact with scope of thought is revealed in individuals with attention-deficit hyperactivity disorder (ADHD), who were suggested to

Box 2. Clinical Perspective of the SoM Framework

Although the alternating nature of SoM is a fundamental characteristic of the human mind, the pattern of the SoM alterations can differ between individuals and during different episodes of our life. Individuals diagnosed with psychiatric disorders can be regarded as having maladaptive SoM distributions, as illustrated in Figure I. Bipolar disorder is a good demonstration of the broad SoM influence over a host of dimensions (beyond the well-known mood fluctuations characterizing this condition). During manic episodes, individuals not only experience elevated mood but also tend to have racing thoughts, exhibit a continuous flow of speech that moves from one topic to another based on thin associations, and have increased attentional distractibility [109]. They further exhibit grandiose behaviors and engage in high-risk activities, but also show increased creativity [110]. During depressive episodes, these same individuals exhibit decreased interest in previously pleasurable activities, a ruminative thinking style, and impaired verbal fluency [84,111]. Interestingly, lithium treatment not only evens-out the mood swings of patients but also affects other cognitive faculties such as diminishing creativity [112]. Under our proposed framework, bipolar disorder can be understood as a tendency to shift between the two extremes of the broad–narrow SoM spectrum (see Figure IB).

In major depression, psychosocial stress or a mild dysphoric state can trigger the initiation of a depressive episode [113]. The term 'depressive interlock' was given to the cycle in which an individual's negative repetitive thinking reinforces his internal depressogenic model that further leads to negative interpretations and depressive body states, giving rise to a self-perpetuating loop of depressive symptoms [114]. This condition can be viewed as perseveration of an extremely narrow SoM (see Figure ID). One method that has been proposed to modify the information processing characterizing depressive interlock is attention control, in the form of mindfulness training. Mindfulness was suggested to induce experiential rather than conceptual processing of information, and to improve an individual's ability to recognize and disengage from maladaptive patterns of thinking [115]. According to our framework, mindfulness may alleviate depressive symptoms by increasing the weight of BU signals at the expense of TD processing. In other words, mood improvement is a byproduct of a shift towards a broader SoM. This indirect influence implies that manipulating other dimensions toward broad SoM may also lead to emotional change. This can be done by engaging in a task that broadens associative thought [33,34], or by manifesting muscular and behavioral actions that correspond to explorative tendencies [116,117].

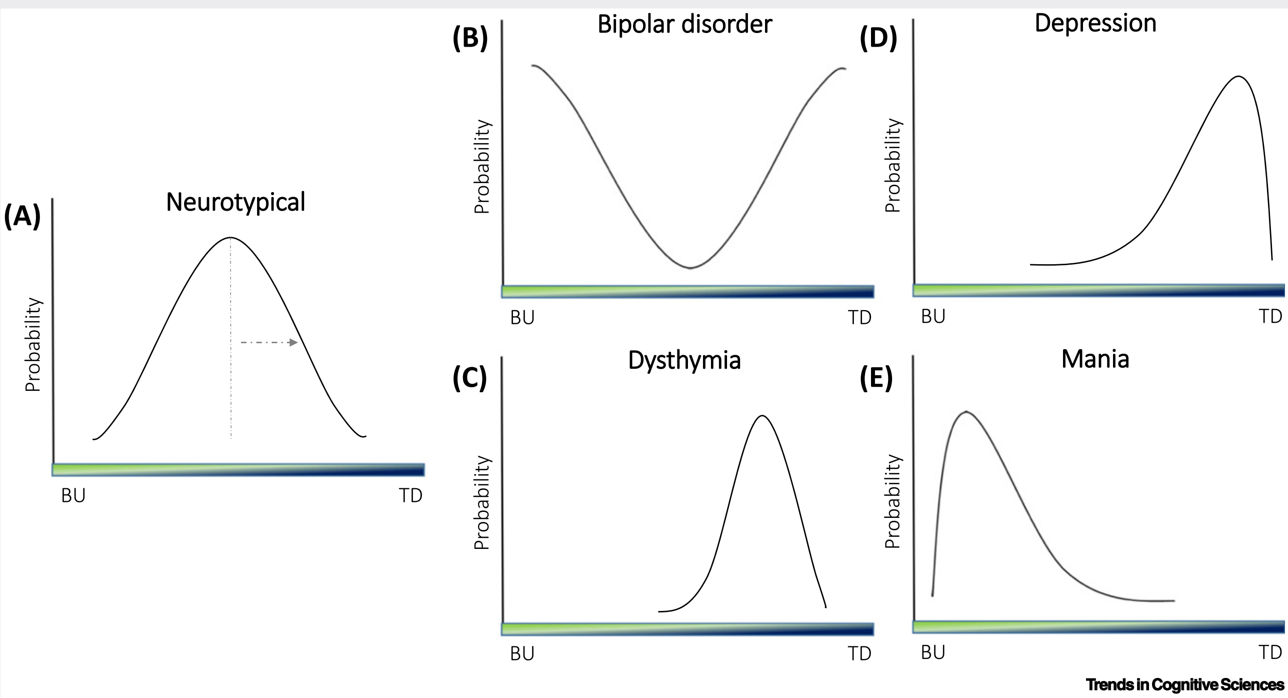

Figure I. Illustration of the Hypothesized Distribution of SoM in Different Clinical Conditions. (A) SoM distribution in neurotypical individuals. The TD:BU ratio varies across different contexts, maintaining a balanced TD:BU ratio most of the time and rarely reaching the extremes of the TD:BU continuum. (B) SoM distribution in bipolar disorder. High probability of reliance upon strong BU or TD signals leads to drastic shifts from broad to narrow SoM. (C) SoM distribution in dysthymia. Low variability of the SoM distribution and a shift in its central tendency towards the TD end leads to low flexibility of SoM alterations and inclination towards narrow SoM. (D) SoM distribution in major depressive disorder. A highly skewed SoM distribution with high probability of reliance upon strong TD signals leads to extremely narrow SoM. (E) SoM distribution under mania. A highly skewed SoM distribution with high probability of reliance upon strong BU signals leads to extremely broad SoM.

exhibit high creativity [63]. Individuals with ADHD outperform non-ADHD individuals in a creative task (divergent thinking) but perform worse on a task necessitating high inhibition (convergent thinking). These results were partly mediated by poor inhibitory control resources in ADHD [64], supporting our proposal that decreased TD inhibitory signals accompany broad thinking. By manipulating inhibitory resources, a more recent study was able to show a causal relationship between inhibitory control and scope of thought. As predicted, depletion of inhibitory resources led to enhanced fluency in a divergent thinking task through enlargement of semantic scope [65].

Scope of thought has been previously proposed to differ between hemispheres. According to this model, the left hemisphere engages in 'fine semantic coding' in which a smaller subset of semantic information with central features is activated in response to an input word, whereas the right hemisphere engages in 'coarse semantic coding', weakly activating larger field of semantic information with more peripheral features to the target word [66]. While this model does not contradict our proposal that high TD signals can lead to narrowed thinking, it raises the interesting question of whether TD signals can be lateralized to confer differing weights in the two hemispheres.

To test the SoM hypothesis that scope of thought interacts with the degree of TD:BU ratio, future studies could induce broad versus narrow thinking styles within individuals and investigate the corresponding change in the activation of neural regions that were previously suggested to be involved in narrowed thinking. One such proposal is to measure the relative activation of the mPFC (TD) relative to the MTL (BU) in an associative thinking task [53]. In a relevant study, an abstract (broad thinking) or concrete (narrow thinking) mindset was induced by manipulating the level of action identification (representation of goal-directed actions as concrete vs abstract) and width of object categories (categorizing objects based on a supraordinate category vs based on specific exemplars) [67]. Adoption of an abstract mindset was associated with activity in posterior regions implicated in visual perception, whereas adoption of concrete mindset was associated with activation in frontoparietal regions implicated in goal-directed action, such as the pre-supplementary motor area [67]. These regions form another putative option for testing the TD:BU ratio prediction.

Openness to Experience

Fluctuations along the exploration–exploitation axis are also suggested to result from changes in the TD:BU ratio. Most theories of predictive coding implement a central error term (prediction error, PE) that signifies the difference between TD expectations and the BU processing of incoming information [68]. A large PE reflects high uncertainty. In exploitation mode, we seek to rely on previous knowledge to minimize PE. Therefore, exploitatory behavior necessitates increased emphasis on TD processing and attenuation of irrelevant BU signals [69]. Conversely, in exploratory mode substantially fewer resources are allocated to minimizing PE. TD information is assigned a smaller weight, resulting in greater openness to novelty, learning, and new experiences. Alertness to detecting interesting, novel, and unexpected stimuli is thus guided by BU processes as well as by large PE values, ensuring that important but unpredictable information is not overlooked [70]. The TD:BU ratio thus dictates our disposition along the exploitation–exploration axis, with higher emphasis on BU in exploration mode, and greater TD weights to elicit exploitation. This proposed mechanism could explain why a similar PE magnitude can elicit anxiety in one SoM (narrow) and thrill in another (broad). The breadth of SoM can directly modulate the subjective experience of exactly the same environment.

A TD mechanism underlying the transition between exploration and exploitation has been proposed [71]. According to this model, the locus coeruleus/norepinephrine (LC-NE) system has two distinguishable modes of activity: a phasic mode underlying exploitatory behavior and a tonic mode underlying exploration. The transition between the two modes is suggested to result from TD information emanating from frontal structures that are responsible for evaluating cost and reward [71]. Our model extends this account by further proposing that the TD signals leading to a transition from exploration to exploitation interact with the TD signals, leading to a transition between other principal dimensions of processing. For example, the LC phasic response underlying exploitation is proposed to facilitate task-relevant behavioral responses by using an attentional filter to select the occurrence of task-relevant stimuli. This attentional selection is equivalent to narrow, local attention. By contrast, tonic LC activity underlying exploration mode leads to less effective engagement in task performance and increased distractibility, equivalent to a state of broader, global attention. Likewise, LC phasic activity is driven by the current reward value of a stimulus rather than by its sensory attributes. As such, the LC phasic response relies on perception that is highly influenced by predictions – TD information about the value of the stimulus rather than BU information. We thus propose that TD signals lead to a multifaceted transition across several dimensions of functioning, of which exploitation–exploration trade-off is one instance.

In accordance with what would be predicted by the SoM framework, cognitive load promotes exploitatory behavior [36]. With regards to exploratory behavior, it can be either random and spontaneous (e.g., looking for interesting opportunities with no specific goal), or directed and intentional (e.g., when looking for a place to hide from a predator). When cognitive control resources are available to constrain behavior, participants explore in a directed manner, whereas when control resources are depleted, participants explore the environment more randomly [36]. Taken together, corresponding studies could be used to identify the ROIs that are relevant for exploration (both directed and random) and exploitation, and subsequently also be used to test the TD:BU ratio in this dimension.

Affect

Affect has a less direct relation with the TD:BU ratio because in the short term both BU and TD processes can lead to similar affective states. Under BU processing, affect is elicited as a direct consequence of perceiving a stimulus with reinforcing or aversive properties [72], whereas under high TD processing affect is shaped by high-level use of emotion regulation strategies [73]. However, in the long term, mood is affected by the TD:BU ratio in the same way as other SoM dimensions. Specifically, we claim that a higher TD:BU ratio will facilitate a negative mood, whereas a lower TD:BU ratio will facilitate a positive mood. First, as described above, TD processes carry with them inhibitory signals that constrict the breadth of associative thinking, at the extreme resulting in pathological ruminations, and more typically simply resulting in negative mood [33,34]. Therefore, less TD weights imply fewer restrictions on associative thinking and a lower tendency for rumination. Second, higher TD weights result in lower processing of unexpected sensory input, leading to low sensitivity to alterations in the environment that could improve mood. In line with this suggestion, individuals suffering from major depressive disorder show hyperactivation of the **default mode network** [74], which was shown to be associated with lower stimulus-driven (i.e., BU) processing [75]. Likewise, mindfulness training was suggested to reduce negative affect by directing attention toward the transitory nature of momentary experience (i.e., increasing BU processing).

Because affect is influenced by the TD:BU ratio in an indirect manner, the ROIs for testing this dimension are not expected to be those that directly subserve the generation of positive versus negative affect. Instead, we propose that the cognitive processes that lead to or maintain negative mood are the ones affected by the TD:BU ratio. According to Beck's cognitive model of depression, dysfunctional negative self-referential schemas play a central part in the maintenance of the disorder and lead to a selective negative bias in interpreting

Box 3. Implications of the SoM Framework

Manipulating SoM can prove beneficial not only for our affective state (Box 2) but also for cognitive functioning. By acknowledging the dimensions of our SoM and the connections between them, we can influence performance to best match the demands of a given situation. For instance, a person working as a computer programmer can encounter different tasks in her job that require different cognitive skills. Some of her work constitutes detailed planning of an algorithm, which can benefit from local and focused attention to the details, exploitatory reliance on her previously acquired knowledge, and narrowing of her associative thinking. Occasionally, she might encounter a new problem that calls for new ideas, alternative ways of thinking, and novel programming skills. Engaging in tasks that induce broad SoM can assist her in fostering the requested transition. Related research has shown that performing particular cognitive tasks can influence the processing resources available for a consecutive task, even when the task requires abilities that were thought to be stable over time [2]. Hence, investigating the dimensions of processing that characterize our SoM and their codependencies can inspire ways for changing our SoM adaptively and compatibly with our current goals.

Fortunately, this idea can be tested experimentally. Finding ways to effectively modulate one dimension of processing (e.g., scope of thought) and investigating its influence over other dimensions of processing, as well as over performance in specific tasks, can reveal the interdependencies between the dimensions of functioning and help in devising ways to boost our performance. For example, broadening the scope of thought through a task that promotes associative progression is expected to decrease the TD:BU ratio by decreasing mPFC inhibition of the medial temporal lobe (Figure I). Such alteration of the TD:BU ratio is expected to affect other dimensions of functioning that rely on the same neural resources.

Apart from modulating SoM using behavioral methods, direct modulation of the neural mechanism underlying SoM (the TD:BU ratio) can be developed using procedures such as neurofeedback [118] or **transcranial magnetic stimulation** (TMS).

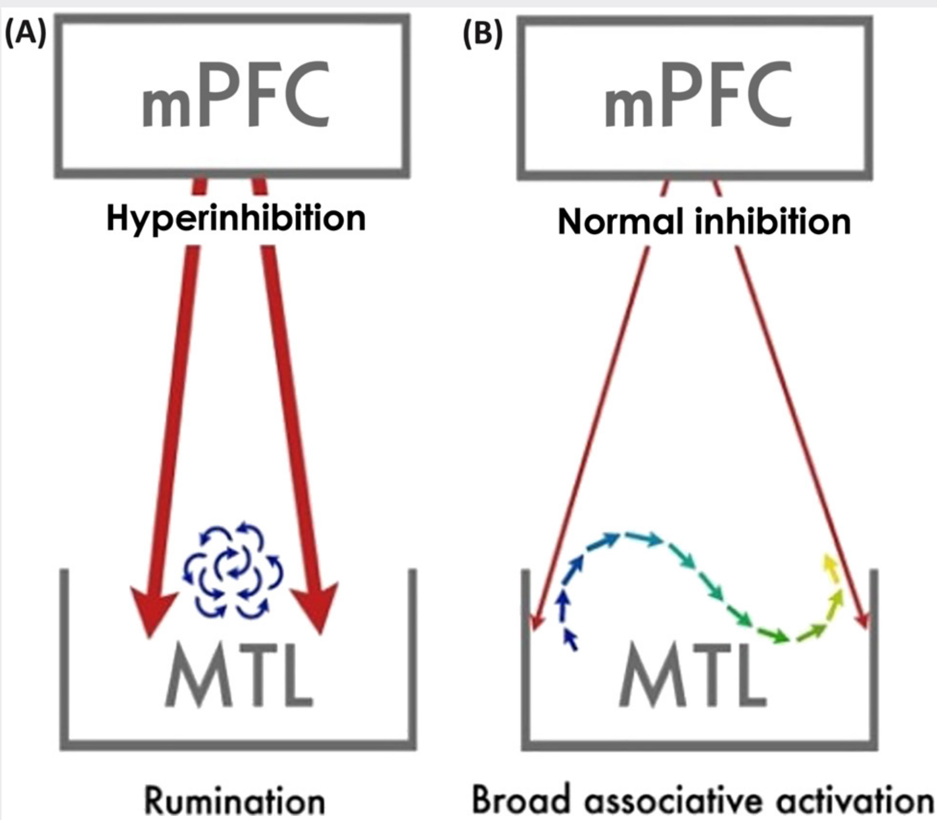

Figure I. Narrow versus Broadly Associative Thinking. (A) The narrow thought pattern involves rumination around a narrow focus. Even if this thought pattern is associative, it is limited in scope. Such constrained thought is proposed to stem from a high TD:BU ratio, manifested as hyperinhibition from the medial prefrontal cortex (mPFC) to the medial temporal lobe (MTL). (B) A broad thought pattern is characterized by a low TD:BU ratio, resulting in broadly associative activation that, although still affected by inhibition signals (for functional guidance), can seamlessly disengage from one focus and advance to another. Modulating the scope of thought is expected to result from a corresponding modulation of the TD:BU ratio underlying this dimension, thus leading to a global change in the SoM dimensions relying on the same neural mechanism. Figure adapted, with permission, from [53].

new experiences [76]. During such negative self-referential processing, increased TD signals from medial prefrontal regions were observed [77]. In line with Beck's theory, depressed individuals [78] and subclinical ruminators [79] show an attentional bias toward negative stimuli, and their difficulty to disengage from these stimuli is thought to exacerbate symptoms of dysphoria. We propose that the increased self-referential processing seen in depression – selective attention to negative stimuli and interpretation of new experiences according to predictions – all rely on increased TD processing and relate to neural pathways that induce a narrowed scope of perception, attention, and thought.

Concluding Remarks

SoMs influence the way we experience our environment, perceptually and cognitively, how we feel, how we decide, and how we act. As such, it is important to have a clear characterization of SoM so as to delineate its dimensions and explain its neural underpinning. In this paper we have proposed a framework for understanding SoM. We suggest that a SoM aligns diverse faculties together via the TD:BU ratio, and we show how these links go high and low in the hierarchy of processing. Although previous accounts argued for some of the interdependencies proposed under the SoM framework (e.g., [4,80,83,92,107]), the current framework defines SoM in an overarching manner to include all facets of our mental life: cognitive, emotional, and behavioral, as well as proposing a unifying neural mechanism for aligning them together.

The SoM theoretical framework sets the stage for further in-depth studies that would test the dimensions of functioning involved in a SoM, the breadth of their reciprocal influences, and the ways to modulate them (see Outstanding Questions). Both the framework of SoM and the proposed TD:BU mechanism can be tested directly. If the principal dimensions turn out not to vary together, or the TD:BU ratios in the relevant TD and BU regions do not change within subjects in accordance with SoM, this would falsify our proposal. Given the converging literature and the synthesis we presented here, however, these hypotheses seem promising. On the practical side (Box 3), understanding which SoM is optimal for specific cognitive tasks, and developing methods for inducing it, has the potential to boost our cognitive competence and our emotional well-being. Importantly, this framework can also help to understand and approach a variety of debilitating and common psychiatric disorders involving abnormal recruitment of one or more of the SoM domains. Thus, SoM is an important target for investigation both for brain science and for clinical fields.

Outstanding Questions

How do BU and TD signals merge in the cortex to give rise to their combined effect? This is a global question with far-reaching implications.

How might neuromodulators, and the balance between inhibition and excitation, interact to generate and/or modulate the TD:BU ratio that gives rise to SoM?

What causes a change of SoM, and how?

What is the relationship between SoM and conscious thought? Can one exert direct voluntary control over the TD:BU balance, perhaps by using **neurofeedback** procedures?

Are there any unique circumstances under which one of the principal elements of SoM is not synchronized with the other elements?

Is there a distinction between SoM and other transient mental states?

Can the TD:BU ratio receive different values in the two hemispheres? For example, is it possible that when the left hemisphere is governed by high TD signals, the right hemisphere accentuates BU processing?

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References

1. Lester, D. (2012) A multiple self theory of the mind. *Compr. Psychol.* 1, 5
2. ErEl, H. and Meiran, N. (2017) A drop in performance on a fluid intelligence test due to instructed-rule mindset. *Psychol. Res.* 81, 901–909
3. ErEl, H. and Meiran, N. (2011) Mindset changes lead to drastic impairments in rule finding. *Cognition* 119, 149–165
4. Liberman, N. and Trope, Y. (2014) Traversing psychological distance. *Trends Cogn. Sci.* 18, 364–369
5. Rattan, A. *et al.* (2015) Leveraging mindsets to promote academic achievement. *Perspect. Psychol. Sci.* 10, 721–726
6. Mrazek, A.J. *et al.* (2018) Expanding minds: growth mindsets of self-regulation and the influences on effort and perseverance. *J. Exp. Soc. Psychol.* 79, 164–180
7. Blakemore, S-J. *et al.* (1999) Spatio-temporal prediction modulates the perception of self-produced stimuli. *J. Cogn. Neurosci.* 11, 551–559
8. Walsh, E. and Haggard, P. (2013) Action, prediction, and temporal awareness. *Acta Psychol.* 142, 1–10
9. Fenske, M.J. *et al.* (2006) Top-down facilitation of visual object recognition: object-based and context-based contributions. *Prog. Brain Res.* 155, 3–21
10. Chaumon, M. *et al.* (2014) Visual predictions in the orbitofrontal cortex rely on associative content. *Cereb. Cortex* 24, 2899–2907
11. Torralba, A. *et al.* (2006) Contextual guidance of eye movements and attention in real-world scenes: the role of global features in object search. *Psychol. Rev.* 113, 766–786
12. Navon, D. (1977) Forest before trees: the precedence of global features in visual perception. *Cogn. Psychol.* 9, 353–383
13. Oliva, A. and Schyns, P.G. (1997) Coarse blobs or fine edges? Evidence that information diagnosticity changes the perception of complex visual stimuli. *Cogn. Psychol.* 34, 72–107

14. Reilly, F. *et al.* (1975) Looseness of associations in acute schizophrenia. *Br. J. Psychiatry* 127, 240–246
15. Nolen-Hoeksema, S. (2000) The role of rumination in depressive disorders and mixed anxiety/depressive symptoms. *J. Abnorm. Psychol.* 109, 504–511
16. Digman, J.M. (1990) Personality structure: emergence of the five-factor model. *Annu. Rev. Psychol.* 41, 417–440
17. McCrae, R.R. (1996) Social consequences of experiential openness. *Psychol. Bull.* 120, 323–337
18. McCrae, R.R. (1987) Creativity, divergent thinking, and openness to experience. *J. Pers. Soc. Psychol.* 52, 1258–1265
19. Silvia, P.J. *et al.* (2009) Openness to experience, plasticity, and creativity: exploring lower-order, high-order, and interactive effects. *J. Res. Pers.* 43, 1087–1090
20. George, J.M. and Zhou, J. (2001) When openness to experience and conscientiousness are related to creative behavior: an interactional approach. *J. Appl. Psychol.* 86, 513–524
21. Fantoni, C. and Gerbino, W. (2014) Body actions change the appearance of facial expressions. *PLoS One* 9, e108211
22. Vasey, M.W. *et al.* (2012) It was as big as my head, I swear! Biased spider size estimation in spider phobia. *J. Anxiety Disord.* 26, 20–24
23. Shiban, Y. *et al.* (2016) Treatment effect on biases in size estimation in spider phobia. *Biol. Psychol.* 121, 146–152
24. Heenan, A. and Troje, N.F. (2014) Both physical exercise and progressive muscle relaxation reduce the facing-the-viewer bias in biological motion perception. *PLoS One* 9, e99902
25. Zajonc, R.B. and Sales, S.M. (1966) Social facilitation of dominant and subordinate responses. *J. Exp. Soc. Psychol.* 2, 160–168
26. Staw, B.M. *et al.* (1981) Threat rigidity effects in organizational behavior: a multilevel analysis. *Adm. Sci. Q.* 26, 501–524
27. Kamphuis, W. *et al.* (2008) Threat-rigidity effects on planning and decision making in teams. In *23th Annual Conference of the Society for Industrial and Organizational Psychology*, pp. 83-16, SIOP
28. Berridge, C.W. and Waterhouse, B.D. (2003) The locus coeruleus–noradrenergic system: modulation of behavioral state and state-dependent cognitive processes. *Brain Res. Rev.* 42, 33–84
29. Aston-Jones, G. *et al.* (1999) Role of locus coeruleus in attention and behavioral flexibility. *Biol. Psychiatry* 46, 1309–1320
30. Campbell, H.L. *et al.* (2008) Increased task difficulty results in greater impact of noradrenergic modulation of cognitive flexibility. *Pharmacol. Biochem. Behav.* 8, 222–229
31. Foulsham, T. *et al.* (2011) Scrambled eyes? Disrupting scene structure impedes focal processing and increases bottom-up guidance. *Atten. Percept. Psychophys.* 73, 2008–2025
32. Kimchi, R. (2014) *The Perception of Hierarchical Structure*, Oxford University Press
33. Chermahini, S.A. *et al.* (2012) Creative mood swings: divergent and convergent thinking affect mood in opposite ways. *Psychol. Res.* 76, 634–640
34. Mason, M.F. and Bar, M. (2012) The effect of mental progression on mood. *J. Exp. Psychol. Gen.* 141, 217–221
35. Westermann, R. *et al.* (1996) Relative effectiveness and validity of mood induction procedures: a meta-analysis. *Eur. J. Soc. Psychol.* 26, 557–580
36. Cogliati Dezza, I. *et al.* (2019) Should we control? The interplay between cognitive control and information integration in the resolution of the exploration-exploitation dilemma. *J. Exp. Psychol. Gen.* 148, 977–993
37. Bar, M. (2009) The proactive brain: memory for predictions. *Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci.* 364, 1235–1243
38. Gilbert, C.D. and Li, W. (2013) Top-down influences on visual processing. *Nat. Rev. Neurosci.* 14, 350–363
39. Rauss, K. and Pourtois, G. (2013) What is bottom-up and what is top-down in predictive coding? *Front. Psychol.* 4, 1–8
40. Melnikoff, D.E. and Bargh, J.A. (2018) The mythical number two. *Trends Cogn. Sci.* 22, 280–293
41. Sarter, M. *et al.* (2001) The cognitive neuroscience of sustained attention: where top-down meets bottom-up. *Brain Res. Rev.* 35, 146–160
42. Kok, P. *et al.* (2012) Less is more: expectation sharpens representations in the primary visual cortex. *Neuron* 75, 265–270
43. Brown, D. *et al.* (1984) Visual sensitivity and mindfulness meditation. *Percept. Mot. Skills* 58, 775–784
44. Dillbeck, M.C. (1982) Meditation and flexibility of visual perception and verbal problem solving. *Mem. Cogn.* 10, 207–215
45. Pourtois, G. *et al.* (2013) Brain mechanisms for emotional influences on perception and attention: what is magic and what is not. *Biol. Psychol.* 92, 492–512
46. Kesner, L. (2014) The predictive mind and the experience of visual art work. *Front. Psychol.* 5, 1–13
47. Bar, M. *et al.* (2006) Top-down facilitation of visual recognition. *Proc. Natl. Acad. Sci. U. S. A.* 103, 449–454
48. Deng, W.S. and Sloutsky, V.M. (2016) Selective attention, diffused attention, and the development of categorization. *Cogn. Psychol.* 91, 24–62
49. Blair, M.R. *et al.* (2009) Errors, efficiency, and the interplay between attention and category learning. *Cognition* 112, 330–336
50. Weissman, D.H. *et al.* (2003) Conflict monitoring in the human anterior cingulate cortex during selective attention to global and local object features. *Neuroimage* 19, 1361–1368
51. Valentine, E.R. and Sweet, P.L.G. (1999) Meditation and attention: a comparison of the effects of concentrative and mindfulness meditation on sustained attention. *Ment. Health Relig. Cult.* 2, 59–70
52. Liu, Y. *et al.* (2014) Top-down modulation of neural activity in anticipatory visual attention: control mechanisms revealed by simultaneous EEG–fMRI. *Cereb. Cortex* 26, bhu204
53. Bar, M. (2009) A cognitive neuroscience hypothesis of mood and depression. *Trends Cogn. Sci.* 13, 456–463
54. Denson, T.F. *et al.* (2009) The angry brain: neural correlates of anger, angry rumination, and aggressive personality. *J. Cogn. Neurosci.* 21, 734–744
55. Ray, R.D. *et al.* (2005) Individual differences in trait rumination and the neural systems supporting cognitive reappraisal. *Cogn. Affect. Behav. Neurosci.* 5, 156–168
56. Johnson, M.K. *et al.* (2006) Dissociating medial frontal and posterior cingulate activity during self-reflection. *Soc. Cogn. Affect. Neurosci.* 1, 56–64
57. Ochsner, K.N. *et al.* (2005) The neural correlates of direct and reflected self-knowledge. *Neuroimage* 28, 797–814
58. Frye, M.A. *et al.* (2007) Increased anterior cingulate/medial prefrontal cortical glutamate and creatine in bipolar depression. *Neuropsychopharmacology* 32, 2490–2499
59. Lemogne, C. *et al.* (2009) In search of the depressive self: extended medial prefrontal network during self-referential processing in major depression. *Soc. Cogn. Affect. Neurosci.* 4, 305–312
60. Williams, L.M. *et al.* (2004) Dysregulation of arousal and amygdala–prefrontal systems in paranoid schizophrenia. *Am. J. Psychiatry* 161, 480–489
61. Hill, K. *et al.* (2004) Hypofrontality in schizophrenia: a meta-analysis of functional imaging studies. *Acta Psychiatr. Scand.* 110, 243–256
62. Kubicki, M. *et al.* (2009) A review of diffusion tensor imaging studies in schizophrenia. *J. Psychiatr. Res.* 41, 15–30
63. Boot, N. *et al.* (2017) Subclinical symptoms of attention-deficit/hyperactivity disorder (ADHD) are associated with specific creative processes. *Pers. Individ. Differ.* 114, 73–81
64. White, H.A. and Shah, P. (2006) Uninhibited imaginations: creativity in adults with attention-deficit/hyperactivity disorder. *Pers. Individ. Differ.* 40, 1121–1131
65. Radel, R. *et al.* (2015) The role of (dis)inhibition in creativity: decreased inhibition improves idea generation. *Cognition* 134, 110–120
66. Beeman, M. *et al.* (1994) Summation priming and course coding in the right hemisphere. *J. Cogn. Neurosci.* 6, 26–45
67. Gilead, M. *et al.* (2014) From mind to matter: neural correlates of abstract and concrete mindsets. *Soc. Cogn. Affect. Neurosci.* 9, 638–645
68. Clark, A. (2013) Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behav. Brain Sci.* 36, 181–204
69. Friston, K. (2010) The free-energy principle: a unified brain theory? *Nat. Rev. Neurosci.* 11, 127–138
70. Bar, M. (2007) The proactive brain: using analogies and associations to generate predictions. *Trends Cogn. Sci.* 11, 280–289

71. Aston-Jones, G. and Cohen, J.D. (2005) An integrative theory of locus coeruleus-norepinephrine function: adaptive gain and optimal performance. *Annu. Rev. Neurosci.* 28, 403–450
72. Ochsner, K.N. and Gross, J.J. (2007) The neural architecture of emotion regulation. In *Handbook of Emotion Regulation* (Gross, J.J., ed.), pp. 87–109, Guilford Press
73. Ochsner, K.N. *et al.* (2004) For better or for worse: neural systems supporting the cognitive down- and up-regulation of negative emotion. *Neuroimage* 23, 483–499
74. Kaiser, R.H. *et al.* (2015) Large-scale network dysfunction in major depressive disorder. *JAMA Psychiatry* 72, 603
75. Weissman, D.H. *et al.* (2006) The neural bases of momentary lapses in attention. *Nat. Neurosci.* 9, 971–978
76. Wright, J.H. and Beck, A.T. (1983) Cognitive therapy of depression: theory and practice. *Psychiatr. Serv.* 34, 1119–1127
77. Yoshimura, S. *et al.* (2009) Self-referential processing of negative stimuli within the ventral anterior cingulate gyrus and right amygdala. *Brain Cogn.* 69, 218–225
78. Gotlib, I.H. and Krasnoperova, E. (2004) Attentional biases for negative interpersonal stimuli in clinical depression. *J. Abnorm. Psychol.* 113, 127–135
79. Beckwé, M. and Deroost, N. (2016) Attentional biases in ruminators and worriers. *Psychol. Res.* 80, 952–962
80. Wakslak, C. and Trope, Y. (2009) The effect of construal level on subjective probability estimates. *Psychol. Sci.* 20, 52–58
81. Chun, M.M. and Jiang, Y. (1998) Contextual cueing: implicit learning and memory of visual context guides spatial attention. *Cogn. Psychol.* 36, 28–71
82. Macrae, C.N. and Lewis, H.L. (2002) Do I know you? Processing orientation and face recognition. *Psychol. Sci.* 13, 194–196
83. Gasper, K. and Clore, G.L. (2002) Attending to the big picture: mood and global versus local processing of visual information. *Psychol. Sci.* 13, 34–40
84. American Psychiatric Association (2013) *Diagnostic and Statistical Manual of Mental Disorders (DSM-V)* (5th edn), American Psychiatric Association
85. Dubois, J. and Adolphs, R. (2016) Building a science of individual differences from fMRI. *Trends Cogn. Sci.* 20, 425–443
86. Greene, A.S. *et al.* (2018) Task-induced brain state manipulation improves prediction of individual traits. *Nat. Commun.* 9, 2807
87. Rabellino, D. *et al.* (2016) The innate alarm circuit in post-traumatic stress disorder: conscious and subconscious processing of fear- and trauma-related cues. *Psychiatry Res. Neuroimaging* 248, 142–150
88. Segal, Z.V. and Ingram, R.E. (1994) Mood priming and construct activation in tests of cognitive vulnerability to unipolar depression. *Clin. Psychol. Rev.* 14, 663–695
89. Serino, S. *et al.* (2015) Out of body, out of space: impaired reference frame processing in eating disorders. *Psychiatry Res.* 230, 732–734
90. Hansen, J. (2019) Construal level and cross-sensory influences: high-level construal increases the effect of color on drink perception. *J. Exp. Psychol. Gen.* 148, 890–904
91. Lewis, M.B. *et al.* (2009) Processing Navon letters can make wines taste different. *Perception* 38, 1341–1346
92. Fredrickson, B.L. and Branigan, C. (2005) Positive emotions broaden the scope of attention and thought–action repertoires. *Cogn. Emot.* 19, 313–332
93. Rowe, G. *et al* (2007) Positive affect increases the breadth of attentional selection. *Proc. Natl. Acad. Sci. U. S. A.* 104, 383–388
94. Wronska, M.K. *et al.* (2018) Engaging in creativity broadens attentional scope. *Front. Psychol.* 9, 1–14
95. Forster, J. and Higgins, E.T. (2005) How global versus local perception fits regulatory focus. *Psychol. Sci.* 16, 631–636
96. Gasper, K. and Middlewood, B.L. (2014) Approaching novel thoughts: understanding why elation and boredom promote associative thought more than distress and relaxation. *J. Exp. Soc. Psychol.* 52, 50–57
97. Baror, S. and Bar, M. (2016) Associative activation and its relation to exploration and exploitation in the brain. *Psychol. Sci.* 27, 776–789
98. McMackin, J. and Slovic, P. (2000) When does explicit justification impair decision making? *Appl. Cogn. Psychol.* 14, 527–541
99. Wilson, T.D. and Schooler, J.W. (1991) Thinking too much: introspection can reduce the quality of preferences and decisions. *J. Pers. Soc. Psychol.* 60, 181–192
100. Dojbak Håkonsson, D. *et al.* (2016) Exploration versus exploitation: emotions and performance as antecedents and consequences of team decisions. *Strateg. Manag. J.* 37, 985–1001
101. Fredrickson, B.L. (1998) What good are positive emotions? *Rev. Gen. Psychol.* 2, 300–319
102. Cohen, J.D. *et al.* (2007) Should I stay or should I go? How the human brain manages the trade-off between exploitation and exploration. *Philos. Trans. R. Soc. B Biol. Sci.* 362, 933–942
103. Greene, T.R. and Noice, H. (1988) Influence of positive affect upon creative thinking and problem solving in children. *Psychol. Rep.* 63, 895–898
104. Isen, A.M. *et al.* (1985) The influence of positive affect on the unusualness of word associations. *J. Pers. Soc. Psychol.* 48, 1413–1426
105. Bolte, A. and Goschke, T. (2010) Thinking and emotion: affective modulation of cognitive processing modes. In *Towards a Theory of Thinking* (Glatzeder, B. *et al*., eds), pp. 261–277, Springer
106. Dreisbach, G. and Goschke, T. (2004) How positive affect modulates cognitive control: reduced perseveration at the cost of increased distractibility. *J. Exp. Psychol. Learn. Mem. Cogn.* 30, 343–353
107. Ashby, F.G. *et al.* (1999) A neuropsychological theory on positive affect and its influence on cognition. *Psychol. Rev.* 100, 529–550
108. Vanlessen, N. *et al.* (2016) Happy heart, smiling eyes: a systematic review of positive mood effects on broadening of visuospatial attention. *Neurosci. Biobehav. Rev.* 68, 816–837
109. Henry, G.M. *et al.* (1971) Idiosyncratic patterns of learning and word association during mania. *Am. J. Psychiatry* 128, 564–574
110. Santosa, C.M. *et al.* (2007) Enhanced creativity in bipolar disorder patients: a controlled study. *J. Affect. Disord.* 100, 31–39
111. Martinez-Aran, A. *et al.* (2002) Neuropsychological performance in depressed and euthymic bipolar patients. *Neuropsychobiology* 46, 16–21
112. Malhi, G.S. *et al.* (2016) The lithium battery: assessing the neurocognitive profile of lithium in bipolar disorder. *Bipolar Disord.* 18, 102–115
113. Segal, Z.V. *et al.* (1996) A cognitive science perspective on kindling and episode sensitization in recurrent affective disorder. *Psychol. Med.* 26, 371
114. Teasdale, J.D. (1999) Emotional processing, three modes of mind and the prevention of relapse in depression. *Behav. Res. Ther.* 37, S53–S77
115. Barnhofer, T. *et al.* (2016) How mindfulness training may help to reduce vulnerability for recurrent depression. *Clin. Psychol. Sci.* 4, 328–343
116. Veenstra, L. *et al.* (2017) Embodied mood regulation: the impact of body posture on mood recovery, negative thoughts, and mood-congruent recall. *Cogn. Emot.* 31, 1361–1376
117. Michalak, J. *et al.* (2014) Sitting posture makes a difference-embodiment effects on depressive memory bias. *Clin. Psychol. Psychother.* 21, 519–524
118. Sitaram, R. *et al.* (2017) Closed-loop brain training: the science of neurofeedback. *Nat. Rev. Neurosci.* 18, 86–100