

# Thinking too much: self-generated thought as the engine of neuroticism

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**Neuroticism is a dimension of personality that captures trait individual differences in the tendency to experience negative thoughts and feelings. Established theories explain neuroticism in terms of threat sensitivity, but have limited heuristic value since they cannot account for features of neuroticism that are unrelated to threat, such as creativity and negative psychological states experienced in benign, threat-free environments. We address this issue by proposing that neuroticism stems from trait individual differences in activity in brain circuits that govern the nature of self-generated thought (SGT). We argue our theory explains not only the association of neuroticism with threat sensitivity but also the prominence within the neurotic mind of representations of information that are unrelated to the way the world is right now, such as creativity and nonsituational 'angst'.**

## The challenge of explaining neuroticism

The personality dimension of neuroticism captures trait individual differences in proneness to negative psychological states of all types. High scorers on neuroticism are especially vulnerable to psychiatric illness and also tend to perform poorly in dangerous jobs, yet are typically more creative than average individuals. Despite its important effects on the human experience, currently we lack a mechanistic neurocognitive account that can explain both the costs and benefits of high scores on neuroticism.

In this opinion article, we propose that the cost and benefits of neuroticism are surface manifestations of a tendency to engage in negatively hued SGT [1]. SGT reflects the capacity for cognition to represent information without an obvious link to the current environment, such as those thoughts that occur during mind wandering or daydreaming. However, these SGT processes are not wholly fanciful, but instead are typically based on prior experience and are especially important in contexts where episodic memory and/or semantic knowledge are needed to make sense of the world. Therefore, the process of self-generation can be conceptualised as a mechanism that allows a stimulus to convey a meaning that goes beyond that prescribed by its veridical features. Viewed from an

individual differences perspective, the capacity to think beyond the current situation explains the vulnerability that neurotic individuals have for negative thoughts and feelings of an apparently abstract nature. Furthermore, we now have evidence as to where SGTs come from, since neuroimaging research has identified that the same brain network (the default mode network) is implicated in the episodic memory and semantic processing that occurs during states of spontaneous thought. The simplest and most elegant explanation is therefore that we use the same process to perform all of these different mental computations and that the tendency to apply these particular brain systems to generate negative thoughts and feelings will be reflected in high scores on measures of neuroticism.

Viewed as a whole, these analyses provide a plausible mechanistic account for the fact that neurotic individuals often experience negative affect even when their environment is benign. Moreover, since SGT is also linked to beneficial outcomes, such as creativity and a patient, long-term style of decision-making, it entails a similar mix of costs and benefits to the neurotic personality profile. Finally, both neuroticism and SGT have been linked to changes in activity in the medial prefrontal cortex, including those examples of SGT that are accompanied by a negative ruminative emotional tone. Altogether, these similarities suggest to us that individual differences in proneness to particular elements of SGT are the root cause (the 'engine') of neuroticism.

## What is neuroticism?

Neuroticism indexes individual differences in proneness to negative thoughts and emotions of all types [2]. It is reliably measured by self-report questionnaires and features in all major descriptive models of personality [3–6]. Neuroticism significantly increases susceptibility to psychiatric illness [7–11] and also modulates risk-related behaviour. For example, high scorers on neuroticism take fewer risks when making investments, an effect that is genetically based [12]. Likewise, neuroticism affects performance in occupations that entail physical danger: low scores on neuroticism are associated with superior performance among bomb-disposal operatives [13]. Similarly, volunteers for military pilot training on average score significantly lower on neuroticism than the general public and those trainees that graduate typically score even lower on neuroticism than their already low-scoring

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peers who fail training [14]. This association appears to stem from the more dangerous nature of military aviation rather than the psychomotor demands of flying aircraft *per se*, because amateur civilian pilots score close to the population average on neuroticism [15]. Other personality constructs also influence performance in military aviation, especially extraversion [15], but recent meta-analytic research comparing the incremental effect of different personality constructs on military aviation success shows that neuroticism exerts the strongest influence [16].

Given that high scorers on neuroticism have difficulty coping with dangerous jobs, it might seem reasonable to explain neuroticism as stemming from a magnified perception of threat; indeed, this hypothesis is a leading causal explanation for neuroticism [17]. However, high scorers on neuroticism are not only highly sensitive to threat but also prone to experiencing negative psychological states in the absence of a current threat stimulus, as demonstrated by the content of neuroticism items in the well-established Eysenck Personality Questionnaire (e.g., ‘Do you ever feel ‘just miserable’ for no reason?’; ‘Are you often troubled about feelings of guilt?’; ‘Do you worry about awful things that might happen?’; ‘Have you ever wished that you were dead?’; ‘Do you worry too long after an embarrassing experience?’) [2]. The content of these items suggests that a cardinal aspect of neuroticism is the tendency to self-generate negative affect, a tendency that casts doubt upon theories that explain neuroticism wholly in terms of threat sensitivity, because these theories can only explain a heightened response to a threat stimulus that is currently present. Instead, our SGT-based theory of neuroticism has the advantage of encompassing threat sensitivity, since it is plausible that a tendency to self-generate negative affect would be a distraction when attempting to defuse a bomb, yet it also explains the proclivity for rumination and abstract ‘angst’ in threat-free situations that is such a prominent feature of the neurotic mind.

### Links between neuroticism and creativity

If it is true that the root cause of neuroticism lies in the tendency to self-generate negatively hued thoughts and feelings, then it is plausible that high scorers on neuroticism should, on average, be more creative problem-solvers than low scorers, because they will tend to dwell on problems to a greater degree than low scorers. This is an important point because a key feature of creative thought is the ability to generate solutions to problems that are distinct from the traditional way the problem is solved [18]. This hypothesis is supported by the stereotype of the brooding, tortured, genius, as well as a variety of empirical evidence. For example, depressive states may facilitate the analysis of complex problems [19]. Additionally, there is evidence that high scorers on neuroticism tend to be more creative than low scorers: a study of 257 professional painters and sculptors living in Germany found that the male artists were significantly more neurotic than the male nonartists [20]. Similarly, individuals working in creative roles in the advertising industry tend to score significantly higher on neuroticism than employees in noncreative roles [21].

These associations between neuroticism and creativity are backed up by epidemiological research showing that

creative professionals have a higher than average risk of both psychiatric illness and suicide [22]. Viewed as a whole, these findings are consistent with the notion that a hyperactive imagination is the root cause of neuroticism, but they do not demonstrate that this is the case.

A clue as to the solution of this problem can be found in the words of Isaac Newton, who viewed his creativity as a product of intense, prolonged rumination: ‘I keep the subject constantly before me, and wait till the first dawns open slowly, by little and little, into a full and clear light.’ [23]. Newton also exhibited signs of being highly neurotic, such as brooding over past mistakes and worrying obsessively about scientific precedence, all of which culminated in a nervous breakdown during the summer and autumn of 1693 [24]. This breakdown could have been a coincidence but, viewed in the light of studies linking neuroticism and creativity, it seems more plausible that the proclivity for prolonged, self-generated rumination that underpinned Newton’s creativity was also responsible for his neurotic symptoms and, ultimately, the collapse of his mental health. In line with this notion, experimental findings show that associations between neuroticism and creativity stem from the problem-solving benefits of rumination-related processes, such as worrying. For example, experimentally induced worry increased creativity in high scorers on neuroticism [25].

### Towards a mechanistic explanation for neuroticism

The two features of the neurotic brain (affective states that are independent of the environment and novel and original solutions to abstract problems) can both be simply accounted for by a mechanism that allows thoughts and feelings to represent states that are unrelated to immediate sensory input, a phenomenon known as SGT (Box 1) [18]. SGT is common across cultures [18] and is fundamentally prospective in orientation [26]. It has been argued that SGT is adaptive because it allows individuals the

#### Box 1. SGT

The content of consciousness does not always directly reflect the events taking place in the immediate environment. Building on work showing that episodic and semantic knowledge is a constructive process, it is hypothesised that states such as mind-wandering or daydreaming are consequences of a similar mechanism(s) that allows us to represent thoughts and feelings that are not present in the immediate environment. One term that captures both the independence of these experiences from the events in the environment as well as their active representational nature, is SGT [1].

- SGT refers to the nature of the process through which an experience is produced; it does not refer to whether an experience is related to an ongoing task. Certain tasks, such as reading, require an individual to elaborate on stimulus input. For example, when reading a detective novel, it is necessary to use a model of the narrative to make inferences about who committed a crime [45]. The extent to which an experience is related to a task depends on whether the process of self-generation is coupled or decoupled from task-relevant events in the environment.

- SGTs do not imply that an experience is intentional. Self-generation is a process that describes how conscious experiences represent information we can not see and/or results from an intrinsic stimulus. It does not describe whether the experiences are intentional. In the same way that a dishwasher can be programmed to initiate a self-cleaning routine without prescribing intention, SGT can be both deliberate and nondeliberate [46].

freedom to bring existing knowledge to bear on current problems, such as making sense of who they are and deciding what to do next [18].

This idea is backed up by the finding that SGT is a vehicle for planning [26,27], creativity [28], and delaying gratification [29]. For example, the structural integrity of regions of the medial prefrontal cortex (mPFC) is predictive of both greater SGT as well as a better capacity to delay gratification [30]. It has been argued that the beneficial functional outcomes linked to SGT reflect the reliance of our species on imagination in navigating the complex social world in which we exist [18]. Since neuroticism reflects both worry and creativity, we suggest that extreme proneness to SGT, arising through individual differences in the structure and function of the mPFC, provides a parsimonious explanation for the neurotic mind.

Importantly, if SGT is a core mechanism in neuroticism, this can explain the tendency among high scorers on neuroticism to represent unpleasant affect in the absence of a stimulus [2]. We base this claim on the finding that SGT can perpetuate unhappiness, presumably because dwelling on negative events from the past or fretting about possible future disasters can extend into the present moment the impact that these episodes have on our happiness [27]. Neuroimaging has provided a viable mechanism in support of this view. For example, SGT is linked to changes in activity in the mPFC and the posterior cingulate cortex (PCC) [18], which are two major hubs of the default mode network (DMN), a network of brain systems that are active during thoughts that are unrelated to external demanding perceptual tasks [29]. Importantly, the mPFC and PCC are also key components of the medial prefrontal network (MPN), a subsystem of the DMN that connects it with affective systems, including the amygdala, medial dorsal thalamus, striatum, hypothalamus, and the midbrain periaqueductal gray (PAG) [31] (Box 2).

Building on these data, research revealed that the mPFC–PCC axis is important in the affective tone of SGT. Multivoxel pattern analysis demonstrated that neural patterns in the mPFC determined the emotional content of SGT [32]. A large-scale individual-differences study exploring the neural correlates of the content of SGT at rest indicated that individuals whose experiences were less positive in tone (akin to being highly neurotic) exhibited greater activity in regions of the mPFC–PCC that are associated with conscious perception of threat [33]. Fitting with these findings is work showing that DMN brain regions were more active during induced worry compared with a neutral condition and that neuroticism correlated positively with the amount of everyday worrying and also with the generation of more worry-related thoughts following exposure to a worry-inducing sentence [34].

Together, these findings suggest that the persistent, rumination-based unhappiness that the neurotic person carries with them even in benign environments (their ‘camel-hump’ of misery) can be conceptualised as blue-tinted SGT generated by tonic differences in the activity in the DMN (and especially in threat-related circuits of the MPN). Stated more briefly, we argue that high scorers on neuroticism are distinguished from low scorers by a

### Box 2. The MPN and SGT neuroticism theory

It has been proposed [31] that the MPN is a key component of the DMN [47]. The PCC and mPFC, both core hubs of the DMN, support spontaneous examples of SGT, such as mind-wandering [39], as well as the cognitive operations that underpin these states, including the imagination of new events and the recollection of episodic memories [48]. The MPN also provides a critical framework from which to understand the relation between creativity, SGT, and negative affect. For example, creativity, worry, criticism, depression, neuroticism, and rumination have been linked to the PCC [49–52], suggesting a functional overlap between these processes. Intriguingly, the MPN not only connects the mPFC–PCC, but also integrates these regions with descending pathways from the amygdala, medial thalamus and midbrain PAG, amygdala, and medial thalamus, all regions known to be involved in negative affect [31]. One speculation is that the mPFC inhibits transmission from the amygdala, bed nucleus of the stria terminalis (BNST), and midbrain regions, including the PAG. The functional relation between the mPFC and PCC is speculative, yet the PCC is part of the episodic and attention systems and may have a role in internally directed self-referential operations [53], while the mPFC may be involved in the regulation and control of cognitive processes through its role in metacognition [54,55]. The mechanism we propose here is that neuroticism is related to trait interindividual differences in activity in the mPFC–PCC SGT pathways. This pattern of activity is beneficial to creativity because it results in higher engagement of imagination and binding of episodic experiences, yet leaves the individual open to rumination, worry, and engagement of descending pathways, thereby increasing the likelihood of negative affect and psychopathology. In this way, the process by which we self-generate cognition can perpetuate the duration of negative affective states.

tendency for their threat-related brain systems to be particularly active, even in an environment that is threat free.

However, this analysis should not be taken to mean that we believe high scorers on neuroticism are prone to misery due to imagining completely fanciful threatening events that have no link to external realities (e.g., the invasion of Earth by aliens in flying saucers). Instead, we suggest that the unhappiness of the neurotic mind is mostly due to threats with some grounding in reality, such as past adversity in the workplace or future risk of spousal infidelity. However, our key point is that, at the moment when the neurotic misery is experienced, the threat stimulus is not present and is, instead, imagined. Therefore, it is this capacity for the self-generation of vivid thoughts concerning nonpresent but nonfanciful threats that we suggest is the hallmark of the highly neurotic individual. Furthermore, we address causality by arguing that this hallmark of neuroticism can be explained as arising from endogenous and possibly genetically based differences in activity in certain parts of the DMN; these are brain circuits that are known to influence proneness to negatively hued SGT and, thus, can be viewed as a plausible neural seat of neuroticism [33].

Our hypothesis that SGT provides the foundation of neuroticism addresses a limitation in prior accounts of the neurotic mind. Research has already established that the ventromedial prefrontal cortex (vmPFC) is a hub that is linked to the emotion-generating apparatus of the amygdala [35] and that the basolateral nuclei of the amygdala (BLA) controls the switch from anxiety-related forebrain activity to panic-related midbrain activity as threat moves closer [36]. In line with this notion, neuroticism positively correlates with amygdala reactivity when subjects are

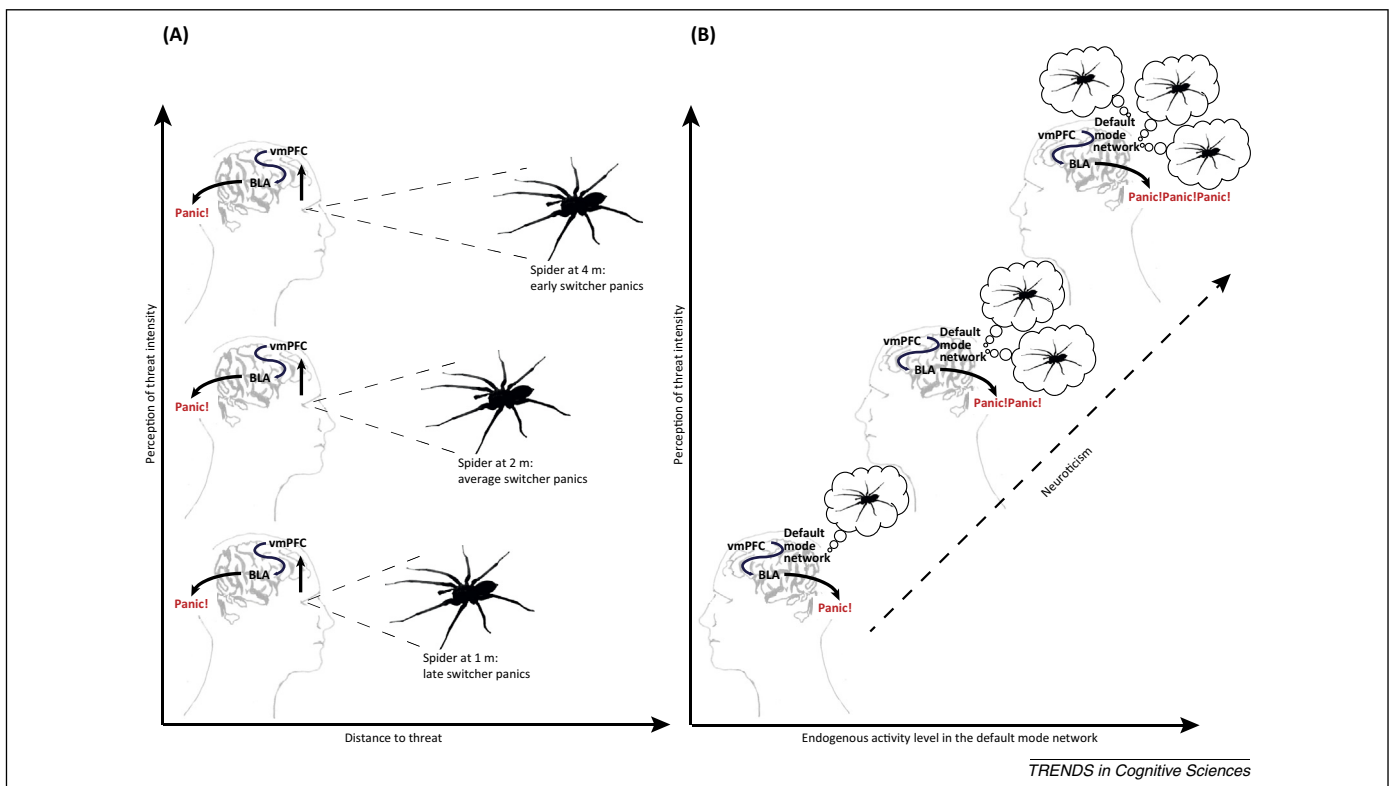
under stress, which in turn, may result in faster switches into higher threat states [37]. Therefore, individuals who happen to have a negatively weighted vmPFC combined with a hyper-reactive BLA should, in response to a threat, switch to panic earlier than an average person (i.e., they will display a magnified perception of threat intensity; Figure 1A).

The model shown in Figure 1A provides a plausible explanation for individual differences in sensitivity to threat, which has been shown to contribute variance to neuroticism [38]. However, this model still requires a threat stimulus to be present in the environment: it cannot explain why high scorers on neuroticism are prone to unpleasant thoughts and feelings when no threat is present [2]. By taking the novel step of recognising interindividual variations in self-generated threat-related cognition as the engine of neuroticism, our model overcomes this problem. Accordingly, if an individual happens to have unusually high levels of endogenous activity in the mPFC–PCC circuits of the DMN, then powerful, threat-related thoughts and feelings can be represented in environments that are threat free, especially in individuals who also have a magnified perception of threat intensity (Figure 1B, Box 3). Therefore, we argue that it is this spontaneous tendency to represent threat-related emotional phenomena that is the true engine of neuroticism. Thus, it is not SGT *per se* that is the cause of neuroticism, but it is when this type of thought turns negative.

### Existing evidence that corroborates our theory

Our SGT-based theory of neuroticism is new and, therefore, has yet to be validated experimentally. Nevertheless, supportive circumstantial evidence is available, such as from studies that show links between individual differences in imagination-related cognitions and individual differences in DMN activity as measured by neuroimaging. For example, when participants executed sequences of verbal and visuospatial working-memory tasks that had been previously practiced, they displayed an increase in both the generation of SGT and activity in the DMN (relative to novel but otherwise identical working-memory tasks) [39]. Furthermore, the magnitude of the increase in DMN activity that the participants displayed while engaged in SGT was positively correlated with the magnitude of their self-reported tendency to daydream, suggesting that endogenous individual differences in the activity of the DMN are responsible for causing trait individual differences in the subjective experience of imagination-related processes. More recently, three studies used online experience sampling to show greater mPFC–PCC activity during periods of SGT [40–42].

Consistent with our hypothesis, activity in the mPFC–PCC is also important in creativity. A Japanese study found that the more creative the participant, the more difficulty they had in suppressing activity in the DMN while engaging in an effortful working-memory task [43]. This latter finding echoes the pattern of costs and



**Figure 1.** Neuroticism, self-generated thought (SGT) and perceptions of threat intensity. **(A)** If an individual with ventromedial prefrontal cortex (vmPFC)/basolateral nuclei of the amygdala (BLA) that is twice as reactive as that of the average person switches from anxiety to panic when a spider encroaches within 4 m (an early switcher), then an average person will switch from anxiety to panic only when that same spider encroaches within 2 m (an ‘average switcher’). Conversely, a person with vmPFC/BLA that is half as reactive as that of the average person will switch from anxiety to panic only when that same spider encroaches within 1 m (a ‘late switcher’). The same psychological state (panic) is achieved in each individual, but the physical distance to threat that elicits it is different. **(B)** A model of how neuroticism is driven by individual differences in susceptibility to negatively hued SGT. Individuals who happen to have greater spontaneous activity in regions of mPFC associated with threat perception, experience frequent, spontaneous activation of threat-related amygdala circuits in situations that are wholly nonthreatening. In individuals who also happen to have a highly reactive vmPFC/BLA, these activations are likely to be sufficiently intense to be debilitating; therefore, such individuals present as being highly neurotic.

### Box 3. Psychiatric relevance of the SGT neuroticism theory: major depressive disorders

A highly ruminative cognitive style, equivalent to a tendency for reverberating self-generated negative cognitions to dominate neutral or positive ones, has been shown to be associated with vulnerability to major depression [56] and severity of depressive symptoms in affected individuals [57]. Increased functional connectivity between core DMN brain structures central to SGTs (vmPFC and PCC) and the subgenual prefrontal cortex (sgPFC) has been postulated to be pivotal in generating self-referential cognitions with the ruminative tone typical of major depression [58]. Our novel cognitive model might help to explain the ruminative thinking pattern seen in depression and is complementary to the already defined role of the sgPFC in the aetiology of mood dysregulation [59]. A diminished top-down dorsolateral PFC control over the DMN is a further plausible addition to the aetiology of the ruminative quality of SGT in depression. This region has been shown to be involved in enabling the shifting in attentional capacity of emotionally relevant self-generated information from negative to positive [60]. Impairment in effective connectivity has been shown in depression between dorsal prefrontal regions and brain networks modulating emotional responses and cognitive function, including the DMN [61]. Hence, a pattern of the ruminative SGT quality that is clinically relevant to depression might be one consequence of a reduction in top-down control exercised by lateral vertical brain networks combined with an increased baseline activity in the DMN modulated by medial brain activity [62]. Clinically relevant treatments have been demonstrated to affect neural and metabolic activity in the sgPFC [63]. The level of activity in the lateral prefrontal brain regions has also been shown to be susceptible to the modification induced by psychological interventions. For instance, mindfulness-based cognitive psychotherapy, an intervention believed to reduce ruminative thinking and risk of further depressive relapses [64], has been shown to increase task-related neural activity in lateral brain networks [62]. SGTs in depression are likely to be influenced by several factors affecting brain structure and function. Epidemiological and clinical variables and individual differences in personality (e.g., neuroticism) are likely contributors to small but significant effects [65] detectible in clinical studies investigating depressive disorders [66].

benefits seen in highly neurotic individuals, who enjoy greater creativity at the expense of less efficient functioning in effortful situations that demand that attention is focussed on the here and now, such as when defusing a bomb or flying a fighter jet in combat.

Further corroborating evidence for our theory is provided by the finding that individuals who have nightmares score significantly higher on neuroticism than nonsufferers [44]. Since nightmares can be conceptualised as a form of unpleasant, threat-related SGT, this finding fits the notion that the unpleasant and unwarranted cognitions that plague high scorers on neuroticism are underpinned by proneness to negatively hued SGT.

### Concluding remarks

In conclusion, neuroticism is one of the most intriguing personality features because its functional correlates capture aspects of the human condition at both beneficial and detrimental ends of the continuum. In this article, we argue that key features of the neurotic mind can be explained by recognising the important role of SGT in this aspect of personality. We hypothesise that the tendency spontaneously to simulate past and future problems explains why neurotic individuals tend to experience unpleasant affect in the absence of any provoking agent. Moreover, because SGT allows us to imagine realities

### Box 4. Outstanding questions

- Theoretical perspectives suggest that the functional outcomes associated with SGT arise either through a person's capacity to control the content of the experience, or the context in which it occurs [67]. These are known as the content and context regulation hypotheses, respectively. A key assumption of this framework is that important elements of the neurotic state emerge from the negative focus to self-generated experience and so would reflect problems in shaping the content of experience away from an unpleasant state. However, these experiences may also emerge at inappropriate times and so reflect problems in exerting control over thought processes. In the future, it may be important to explore whether the neurotic basis to the mind-wandering state depends only on the content of the experience or whether it also reflects problems in limiting these experiences to an appropriate context.
- How do nature and nurture interact to shape the neural mechanisms and connectivity profiles that form the causal underpinnings individual differences in SGT-proneness and, thus, neuroticism? For example, it might be the case that traumatic childhood experiences increase connectivity between global brain circuits involved in SGT, but only in individuals with certain genetic variants.

different to way they are right now, we argue that it underpins our capacity to solve problems in creative and original ways, which is a particularly common gift among high scorers on neuroticism. Thus, our theory can explain why neurotic individuals tend to do well in creative professions but poorly in occupations that demand the individual's attention is constrained to the moment (such as combat aviation). It also suggests that deliberately managing SGT so that it acquires a positive slant (as in meditation-based therapies) is likely to be psychologically protective but, if improperly trained, can do more harm than good. Future work may extend our understanding of beneficial and detrimental elements of the human condition by exploring the intersection of neuroticism with the nature and form of the thoughts that characterize our experience when we are not engaged with the world around us (Box 4).

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