

article has fundamental problems. The article contains no formal description of possible actions. Kurzban et al. arbitrarily select possible actions for each situation considered in the article. However, such an approach is wrong, because the number of possible actions is potentially infinite in any situation (Russell & Norvig 2003). Because possible actions can be very different, the unconscious comparison of their utilities seems impossible. Kurzban et al. do not explain how the mind compares doing math calculations and mind wandering. The functioning of the hypothetical mechanism is described abstractly without pointing to the situations in which mental effort and boredom occur (see the target article's Figure 1). As a result, it is unclear why the output of this mechanism is mental effort and fatigue rather than, for example, fear and anxiety. Fear and anxiety can obviously be applied to optimize costs and benefits.

Another model can be sketched as an alternative to the authors' approach and the theories of depleting resources. Some details should be specified prior to the description of the model. Mental effort and fatigue occur in two sorts of situations. First, mental effort and fatigue usually occur when an individual attempts to acquire novel skills. However, this activity is typically not perceived as boring and negative. As an individual acquires a novel skill, the feeling of mental effort usually disappears (Logan 1985). It is reasonable to assume that in this case mental effort simply reflects the necessary restructuring of the mind. Second, mental effort and fatigue frequently occur when the mental activity of an individual is not difficult but is long-term. In this case, mental effort is perceived as aversive. Obviously, the experiments in the target article were simple but long-term mental activities. The proposed model deals with such situations.

The proposed alternative model is based on two assumptions. First, the mind is able to maintain several processes in parallel. One of the processes is a task which occupies the focus of consciousness while other processes function in a background mode. Second, pursuing a long-term goal is usually an execution of a limited number of actions; many of them should be performed over and over again. As a result, any long-term activity is a sequence of recurring actions and therefore it is monotonous.

The brain has two systems that process monotony and its antagonist, novelty. One system is associated with the hippocampus (Grossberg & Merrill 1992; Vinogradova 2001). This system has a representation of the ongoing situation and compares it with the input from other brain systems. A mismatch between the representation and the input means that the situation is changed, and then the brain is activated. If the representation matches the input, then habituation occurs and the brain activity is decreased (Vinogradova 2001). The second system is the novelty-seeking system, which is responsible for seeking novel and varied sensations and experiences (Roberti 2004; Zuckerman 1994). The functioning of this system is associated with the interaction between neurotransmitter systems that are concentrated in the limbic areas of the brain (Zuckerman 1996).

It can be hypothesized that the monotony of long-term activities leads to the engagement of both novelty-processing systems. The first system attempts to inhibit the ongoing task, and the second system tries to activate any parallel processes. The feeling of mental effort reflects the competition between the task, which suffers from inhibition, and other processes. Fatigue and boredom mirror the inhibition of the ongoing task and habituation. The reduction of performance in tasks such as vigilance tasks results from the inhibition of the task by the first system. Accordingly, changes in the situation may result in the improvement of performance owing to the activation of the brain by this system. The decrement in performance when participants perform sequentially several tasks can be explained on the basis that these tasks share the common experimental context (one experimenter, one room, etc.), and therefore the situation can be considered monotonous.

The relationship between reward and fatigue can be hypothesized as a consequence of the interaction between the novelty-

processing systems and the reward system. Indeed, novelty seeking should be maximally intense in neutral situations, because seeking novel sensations in very dangerous or very pleasant situations is hardly a useful strategy. As a result, reward can inhibit the novelty-processing systems, thereby decreasing the feeling of fatigue.

The feelings of fatigue and boredom in long-term activities possibly reflect a conflict between various brain systems. In my opinion, the ability to pursue long-term goals having no innate basis is the main characteristic distinguishing humans from other animals (Prudkov 1999; 2005). The experiments described in the target article are obvious examples of pursuing such goals. Indeed, subjects participated in the vigilance tasks not because they were hungry, sexually unsatisfied, or frightened. The ability is maintained by the prefrontal lobes (Luria 1966; 1982). This is a young structure maximally advanced in humans (Luria 1966).

However, long-term activities often are monotonous. Monotony results in the activation of the novelty-processing systems. These systems are maintained by ancient limbic structures, which also maintain other biological goals (Kolb & Whishaw 2003). For the novelty-processing systems, pursuing social goals is a neutral situation because the limbic structures are weakly involved in processing social goals. Therefore, in this case the novelty-processing systems should be activated, thereby hindering social activities.

Kurzban et al. ask, "Why, if revising a manuscript contributes to the achievement of key long-term goals, does it feel aversively 'effortful'?" (sect. 2.1, para. 4). They attempt to respond to this question, but the target article does not contain a clear answer. The proposed model, however, offers a simple solution: because a mature scientist frequently revises manuscripts and this activity becomes monotonous.

Subjective effort derives from a neurological monitor of performance costs and physiological resources

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Abstract: Kurzban et al.'s expectancy-value mechanism of effort allocation seems relevant in situations when familiar tasks are initiated. However, we think additional mechanisms are important when people continue with a task for a prolonged time. These mechanisms, which are particularly relevant for performance of novel or urgent tasks, involve neural systems that track performance costs and resources.

Why are some tasks experienced as more effortful than others? To address this question, it is useful to distinguish between *reactive* action control in unpredictable environments and *predictive* control in predictable environments. These different types of action control are supported by different brain systems. Predictive control areas are associated with the dorsal prefrontal cortex, dorsal anterior cingulate cortex (dACC), and dorsal striatum, which sustain feedforward action control in tasks that are familiar and predictable (Luu et al. 2011; Tops & Boksem 2011; 2012). By contrast, reactive control areas include the inferior frontal gyrus

(IFG) and anterior insula (AI), which sustain momentary feedback-guided control when tasks are performed that are novel, urgent, or unpredictable. Reactive control thus represents a specialized mode of operation for detecting new information, encoding it in memory, and assimilating it into preexisting knowledge structures, and for changing earlier schemata, thereby facilitating future predictive control (Hasher & Zacks 1979; Tops & Boksem 2011). Because reactive control reduces predictive homeostatic regulation of the internal milieu (discussed below), such cognitive control requires the momentary tracking of physiological costs and resources and is experienced as effortful. The experience of effort is hence an adaptive motivational mechanism that limits the (re-)initiation and prolonged performance of tasks that demand reactive control, especially when there are insufficient perceived benefits, threats, or resources to compensate for the physiological costs of reactive control (Boksem & Tops 2008).

The notions of predictability and controllability are central to understanding which challenges trigger a physiological stress response (Sapolsky 2005). Physiological responses to challenge parallel the two forms of action control: *Reactive* homeostatic responses arise in relation to changes in physiological variables that have already occurred, and *predictive* homeostatic responses emerge in anticipation of predictably timed challenges (Moore-Ede 1986; Romero et al. 2009; cf. Landys et al. 2006). When a challenge or task is perceived as predictable and controllable, because resources are perceived to be sufficient for the task (e.g., enough muscle strength), predictive homeostasis is maintained and the task may not be experienced as effortful. By contrast, situational novelty (e.g., Hasher & Zacks 1979; Shiffrin & Schneider 1977) and unpredictability of cognitive operations (Ackerman 1987; Fisk & Schneider 1983) require effortful processing and can trigger reactive physiological responses that potentially incur health costs (Romero et al. 2009). Importantly, reactive homeostatic control may decrease less urgent predictive homeostatic regulation, causing “somatic neglect” of, for example, circadian variation in appetite (Koole et al., in press).

Neuroimaging evidence supports our thesis that reactive control systems translate information about action costs and resources into a motivational feeling of effort. Through its reciprocal connections with autonomic and visceral centers of the nervous system such as the hypothalamus (Carmichael & Price 1995), the AI may be involved in the monitoring and regulation of peripheral resources such as glucose levels (Allport et al. 2004), muscle condition (Craig 2003), autonomic activation (Critchley et al. 2004), and the processing of aversive bodily states (Paulus & Stein 2006). In addition, insula activation has been related to the subjective perception of physical effort and exertion (de Graaf et al. 2004; Williamson et al. 1999; 2003). The IFG/AI areas that are active when people experience subjective effort are also implicated in compensatory effort allocation with time on task. One study found the bilateral AI to be involved in assessing the level of energy expenditure required to reach a proposed effort (Prévost et al. 2010), while several other studies suggested that increased attentional effort during performance over extended periods of time or after sleep deprivation is associated with increased activation of right-hemisphere ventral cortical areas including IFG/AI, and sometimes in the context of activity declines in dACC and/or the dorsolateral prefrontal cortex (Bell-McGinty et al. 2004; Chuah et al. 2006; Coull et al. 1998; Paus et al. 1997; Walker et al. 2005). Moreover, momentary lapses in attention, which increase with time on task and fatigue, are associated with reduced activity in this right ventral attentional network, whereas its compensatory recruitment during subsequent trials is associated with recovery from lapses in attention (Weissman et al. 2006).

Thus, the AI may influence action-selection by monitoring the availability of resources and the physiological costs associated with actions. The readout of this monitor may be experienced as feelings of effort, resistance, and discomfort that influence choices to initiate or (dis)continue task performance (Tops & de Jong 2006).

Unlike what Kurzban et al. propose, increased subjective effort does not *necessarily* shift engagement towards alternative, more rewarding options, but may also stimulate disengagement, inactivity, and recuperation when perceived resources (as signaled by the AI) are low (Boksem & Tops 2008). In our view, this is the most important role of subjective effort in decision-making. Indeed, effort may be considered as an adaptive signal that the present behavioral strategy is no longer appropriate, because it continues to demand reactive control that usurps costly physiological resources when substantial resources have already been invested and the goal evidently has not yet been achieved. Feelings of effort may provide the cognitive system with a signal that stimulates lowering of current goals and/or seeking of less demanding alternative strategies.

A major advantage of our account over Kurzban et al.’s is that ours more precisely explains which tasks trigger subjective effort and fatigue (i.e., those that require reactive control, such as tasks that are novel or urgent). Moreover, our account is able to address the transition of prolonged effortful demand into persistent forms of fatigue. When the situation is uncontrollable, individuals are forced to rely on reactive control, associated with feelings of effort, up-regulation of reactive homeostatic responses, and decreased predictive homeostatic regulation. Although adaptive in the short-term when dealing with important and urgent situations, prolonged reactive homeostatic control can lead to enduring physiological changes (Romero et al. 2009), which may give rise to chronic fatigue.

The economics of cognitive effort

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Abstract: If cognitive effort indexes opportunity costs, it should be investigated like other cost factors including risk and delay. We discuss recent methodological advances in behavioral economics and neuroeconomics, highlighting our own work in measuring the subjective (economic) value of cognitive effort. We discuss the implications of Kurzban et al.’s proposal and how some of its predictions may be untestable without behavioral economic formalisms.

Kurzban and colleagues posit phenomenal effort as a marker of opportunity cost, and thus as input to an economic decision about the subjective value of cognitive engagement. As such, cognitive effort is ripe for behavioral economic investigation. If effort represents a cost, formalisms developed in behavioral and neuroeconomic research can be used to quantify that cost. Moreover, many of the extensive implications of the authors’ hypothesis may be untestable without objective cost measures. To distinguish their proposal from resource models, Kurzban et al. suggest indexing effort expenditure with performance. As we discuss below, however, performance has a complicated relationship with effort. Furthermore, humans can make effort-based decisions in an offline manner (i.e., during an unengaged period); this points to the need for offline indices of cognitive effort. The full potential of Kurzban et al.’s essentially economic theory will only be realized once variables of interest are formalized within a behavioral economic framework.

Broadly, behavioral economics is concerned with formal methods for probing the influence of choice dimensions on decision-making. The discipline has yielded a wealth of information about the extent to which cost factors, including delay