CHAPTER TWO

Strength Model of Self-Regulation as Limited Resource: Assessment, Controversies, Update

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Abstract

The strength model of self-regulation holds that self-regulation operates by consuming a limited energy resource, thereby producing a state called ego depletion in which volition is curtailed because of low energy. We present our research program on ego depletion as well as much relevant work contributed by others. Challenges to the theory have emphasized allocation rather than depletion of resources, research participant expectations and obligations, changes in motivation and attention, beliefs and implicit theories, perceptions about depletion and vicarious depletion, glucose anomalies, and feelings of autonomy. We conclude that the theory needs revision and updating to accommodate the new findings, and we indicate the requisite changes. Furthermore, we conclude that the strength model is much better able than the rival accounts to explain all available evidence. Most of the rival accounts are compatible with it and indeed work best by sustaining the assumption that self-regulation relies on a limited resource.

Self-regulation, as the ability to alter one's responses based on rules, goals, ideals, norms, plans, and other standards, has greatly expanded the diversity of human adaptive behavior. It is highly conducive to the biological success of humankind, insofar as the species's remarkable reproductive success and population increase have been mediated by creating cultural societies, which depend on self-regulation. Abundant evidence has linked good self-control to scholastic and occupational success, stable and satisfying close relationships, good mental and physical health, avoidance of crime and violence, good adjustment, overcoming prejudice, healthy lifestyles, resistance to addiction, positive emotional outcomes, and longevity (Baumeister, Heatherton, & Tice, 1994; Daly, Baumeister, Delaney, & MacLachlan, 2014; Deary, Weiss, & Batty, 2010; Finkel, DeWall, Slotter, Oaten, & Foshee, 2009; Gottfredson & Hirschi, 1990; Mischel, Shoda, & Peake, 1988; Moffitt et al., 2011; Muraven, 2008, 2010; Shoda, Mischel, & Peake, 1990; Tangney, Baumeister, & Boone, 2004).

Self-regulation has thus done wonders for humankind, individually and collectively. Yet this positive picture is darkened by a broad sense that people lack sufficient self-control and often fail in their efforts to regulate themselves. In large international surveys of personal strengths and weaknesses, people are less prone to name self-control than any other virtue as a personal strength—and more likely to cite poor self-control as a personal weakness (Baumeister & Tierney, 2011). Many social and personal problems have self-regulatory deficiencies as a central aspect. For example, Gottfredson and Hirschi (1990) proposed that low self-control is the single most important

trait for understanding criminality. Conscientiousness (which consists of self-control plus some additional factors) predicts longevity, and people who lack that trait die younger than others, partly because they drink alcohol, overeat, and smoke more than others (Turiano, Chapman, Gruenewald, & Mroczek, 2013).

The goal of this chapter is to advance a theory of self-regulation as involving consumption of a limited energy resource, informed by recent findings and criticisms. To anticipate our conclusion: The strength model is in need of updating and a revised version of it can account for the evidence better than any currently available alternative. The early, simple notion that ego depletion effects indicate that the brain has run out of fuel is no longer tenable. However, selective allocation of a precious, limited resource is an important component of self-regulation. Most likely, the brain and associated psychological systems monitor energy consumption and curtail energy outlays, not just when energy is gone, but when current allocations occur at an unsustainable rate. Further allocation of depleted resources can occur when current demands are exceptionally high, current tasks have motivational priority, and/or replenishment is imminent, but there may be a natural tendency to resist drawing down energy stores too far or too rapidly.

1. EGO DEPLETION AND SELF-REGULATION THEORY

The ideas that the human self was composed partly of energy and that its activities consumed energy were largely absent from theories about the self for many decades. Baumeister, Bratslavsky, Muraven, and Tice (1998) coined the term *ego depletion* in homage to Freud, who had proposed that the human self was partly composed of energy. Subsequent to Freud, however, the major theories emphasized self-awareness, beliefs about the self, and self-evaluations, with little room for discussion of energy (Carver & Scheier, 1981, 1982; Duval & Wicklund, 1973; Epstein, 1973; Erikson, 1968; Higgins, 1987; Markus, 1977; Markus & Nurius, 1986; McAdams, 1985; Mead, 1934; Shrauger & Schoeneman, 1979; Swann, 1985; Wicklund & Duval, 1971; Wylie, 1979). After reviewing diverse research literatures on self-regulation in the 1980s, Baumeister et al. (1994) proposed that many findings suggested that some energy process could be involved. They speculated, moreover, that the failure of self theory to provide a viable theory of agency could be attributed to the handicap of refusing to countenance energy models. The emergence of an energy perspective on human

agency has stimulated abundant research and theorizing into this hitherto neglected but centrally important aspect of the human self. Some of that work has been overtly skeptical and critical of the idea that the self uses energy in its executive activities. Other work has accepted the premise that energy is involved but has proposed refinements and additions to the basic idea.

1.1 Definitions

We define s*elf-regulation* as processes by which the self intentionally alters its own responses, including thoughts, emotions, impulses, performance, and behaviors, based on standards. *Standards* are ideas about how something should or should not be. They include goals, norms, values, morals, laws, expectations, and comparable responses by others or by oneself in the past. Moreover, our focus is on effortful self-regulation, which means the person exerts effort to bring about the change. We thus do not address whether (and if so, to what extent) the self can also be regulated automatically, without effort. We use the term *self-control* largely interchangeably with self-regulation, although self-control can also be used to refer to the trait of being chronically good or bad at self-regulation.

Ego depletion refers to a state of diminished self-regulatory resources. The use of the term *ego* is simply meant to imply that the resource constitutes part of the self, and it is not meant to invoke Freudian theory generally. Furthermore, ambiguity may arise because the term "depletion" can refer to partial or total exhaustion of the resource. We use the term in its broader sense, referring to any diminishment of resources. Indeed, we are not convinced that people ever reach a point at which the resource is entirely gone.

1.2 Gist of Original Strength Model

The core idea behind the strength model is that self-regulating depends on a limited resource, akin to energy, that is expended and thereby depleted by acts of self-regulation. The original studies on ego depletion were influenced by cognitive load effects, which treat attention as a limited resource, so that when attention is devoted to one stimulus, there is less available to attend to other phenomena (eg, Gilbert, Pelham, & Krull, 1988). One key difference has to do with after-effects. Whereas attention regains its full capacity as soon as the stimulus load is removed, a limited energy resource may take more time to recover, so the impairment will linger. Recent work has found

additional differences between cognitive load and ego depletion, including vulnerability to intrusive negative feelings (Maranges, Baumeister, & Schmeichel, 2016).

The original depletion theory was that some limited resource is used for self-regulation and thereby becomes depleted, leaving less available for subsequent tasks and demands. The well-replicated decline in performance caused by initial self-regulatory exertion (the basic depletion effect) was assumed to reflect lack of energy needed for self-regulatory processes. That was soon amended to indicate that significant resources remained but were being conserved (Muraven, Shmueli, & Burkley, 2006).

The strength model emphasizes that a common resource is used for many different tasks and functions, including self-regulation of diverse responses. The research on depletion has exemplified this by showing that exerting control over one type of response impairs subsequent control over different responses (eg, Baumeister, Vohs, & Tice, 2007). Recent work has continued to indicate that one common resource is involved. Indeed, even the same brain regions in the prefrontal cortex are activated for inhibiting motor responses, restraining addictive cravings, and controlling emotion (Tabibnia et al., 2014).

The strength model bears some resemblance to lay intuitions and folk notions of "willpower," a presumptive source of energy that can be devoted to some undertaking or withheld according to conscious decisions by the individual. The power aspect of willpower may derive from the subjective impression that some temptations are stronger than others—so that the self requires equal or greater strength in order to resist successfully.

The term *energy* is widely used in both literal and metaphorical ways. Willpower can be conceptualized as a psychological resource or a physiological one. For the present, it seems safest to use the term in the metaphorical sense, although we shall address efforts to establish a (literal) physiological substrate involving the human body's energy. Assorted evidence has linked glucose to self-control (see below), but there is no basis for assuming that it is the sole physiological substrate. Equating willpower with glucose may have been tempting but seems an oversimplification.

In any case, the assumption is that acts of self-control tax one's strength or deplete one's resources, and that afterward there is a period of reduced capacity for further self-regulation. Self-regulation is thus costly in the short run and subject to fluctuations in capacity, which would underpin within-person variations in self-regulatory performance.

1.3 Updated Version of Strength Theory

Laboratory testing of the strength model began 20 years ago, and as one would hope, the rich assortment of new findings has introduced complications. In a later section, we will consider alternatives and challenges to the theory. Here, we briefly present an updated version of the strength model.

The idea that self-control depends on a limited energy resource emerged mainly from behavioral data reviewed by Baumeister et al. (1994). In the subsequent decades, much evidence has confirmed this pattern: After exerting and thereby presumably expending energy, people are less willing or able to exert further self-control. However, complicating this picture, much evidence has also showed that ego depletion patterns do not reflect a simple absence of fuel for the brain. Crucially, many manipulations have been shown capable of overcoming depletion effects, indicating that energy could indeed be found for self-control despite depletion. Also, efforts to delve into the physiology of the resource have yielded mixed results. Ample evidence indicates that glucose has some role, but that is likely not the full story. Indeed, as Beedie and Lane (2012) and others have pointed out, the human body still has plenty of reserves of glucose even after severe exertion. We agree with their conclusion that selective allocation of glucose, as opposed to danger of running out of it, should be the focus of theorizing.

Still, ingesting a dose of glucose has been shown to counteract depletion effects reliably (eg, Gailliot, Baumeister, et al., 2007; Gailliot, Plant, Butz, & Baumeister, 2007; Masicampo & Baumeister, 2008), whereas an equally tasty drink with glucose-free diet sweetener has no effect. That fits the view that glucose is involved. It does not mean that the brain is dependent on the new glucose. Rather, the body may allocate more freely when it knows it is getting more.

Thus, the data have brought us to an impasse. Self-regulation requires and consumes glucose. The body responds by conserving its remaining glucose, and that is what creates ego depletion effects. But the body does this long before it is in any serious danger of running out of glucose.

A creative resolution was recently put forward by Evans, Boggero, and Segerstrom (2015). They build on theorizing about physical muscle fatigue by Noakes (1997), which dealt with a similar impasse: Physical muscles feel tired and conserve energy long before they reach the physiological point of being unable to function properly. Muscles do indeed consume energy when engaged in strenuous activity, but the feeling of fatigue that persuades the person to reduce exertion and conserve energy is not closely linked to

physiological incapacitation. Noakes proposed that there is a mechanism he dubbed the central governor, which observes exertion and generates feelings of fatigue—but it functions on the basis of only limited information, so that its processes reflect educated guesswork and estimation rather than direct monitoring of resource availability.

Applying this model to ego depletion, Evans et al. (2015) propose that ego depletion stems from guidance by a central governor that recognizes self-regulatory exertion and seeks to conserve glucose but is not fully informed of the body's glucose stores. Modern, Western, well-fed research participants do not actually face the prospect of running out of glucose during a brief experiment. But their bodies act to conserve glucose when they note that some has been expended.

Several additional facts increase the plausibility of this solution. First, glucose is stored in many places in the body, so a central governor would not likely receive updated inventories. Instead of counting how much is left, it simply notes that some has been expended. Various writers have begun to suggest adenosine as a key aspect. Adenosine is a byproduct of glucose metabolism, and its buildup is associated with feelings of fatigue. To use a crude metaphor, the central governor counts the ashes as a rough sign of fuel burning, rather than being able to count the amount of fuel remaining.

Counting the ashes rather than the remaining fuel is also a system that seemingly works based on extrapolating from short-term data. The governor does not wait until fuel is nearly gone to cause ego depletion. Rather, it simply registers that fuel is being consumed at a rate that would be unsustainable over a long period. Put another way, it is not that the body is in a crisis of low glucose, but merely that its current rate of consumption would potentially create such a crisis. That is why ego depletion effects begin after seemingly minor, brief exertions of self-control. It also explains why incentives, beliefs, and other situational factors can counteract mild depletion: There is still plenty of fuel, and if there is a good reason to keep exerting, one can do so for a brief period.

Moreover, a narrow focus on glucose in self-regulation may miss the big picture. The central governor is not specifically concerned with self-regulatory exertion but with the total picture of conserving glucose. Self-control may be a relatively minor user of glucose, in contrast to other, evolutionarily earlier users. The immune system in particular is a highly variable and therefore occasionally heavy consumer of glucose (Wolowczuk et al., 2008). In evolutionary history, it may have been invoked often

(eg, to fight infections from cuts and bruises), and of course that applied to many individuals with little body fat and unreliable daily glucose intake. The central governor thus presumably placed a high priority on conservation, not primarily to respond to extraordinary demands for self-control, but rather to respond to physical immune challenges.

Exerting self-control may pose little danger of a glucose shortfall extending to compromising the immune system among modern, well-fed American college students (who make up the majority of research participants). Things may be quite different, however, among our evolutionary ancestors and even among modern contemporaries living in less plush environments. Miller and colleagues (Brody et al., 2013; Miller, Yu, Chen, & Brody, 2015) found that low-income African-American participants had worse health to the extent that they exerted more self-control. Behaviorally, they were better off, as indicated by low rates of aggression, smoking, truancy, and the like. But their bodily health was significantly worse, even extending signs to premature aging as seen in cellular and metabolic changes. The idea is that exerting self-control in conditions likely to be disorganized, that encourage acting on problematic urges, and that demand repeated decisions taxes self-control resources with little chance for replenishment (Vohs, 2013). These findings suggest that allocating more glucose to self-control can be damaging to physical health, especially in a stressful environment. Hence we should not be surprised that people evolved to conserve glucose.

One might think that the adaptive solution would simply be to keep a higher level of glucose circulating in body and brain, so there would be more available when needed, so as to be ready for immune challenges, self-regulation, and other demands. In short, the governor could function much the same but in a more liberal regime. There are, however, risks and costs associated with elevated glucose. Diabetics suffer neuropathy (nerve cell deterioration) as a result of high glucose levels—suggesting that keeping more glucose in the brain's self-regulatory centers could damage those brain centers. Moreover, recent evidence suggests that an excess of blood glucose can serve as inviting fuel for pathogens, from bacterial infections to cancer (Peng et al., 2015; Rayfield et al., 1982). Ingesting new glucose presents an opportunity for those pathogens. Hence it is better to keep the stores full rather than constantly depleting and replenishing them, to the extent this is possible. The most effective central governor would therefore allocate glucose judiciously, so as to make few demands on stored glucose and to keep blood glucose levels from getting either too high or too low.

2. SUMMARY OF MAIN FINDINGS AND PHENOMENA

This section will lay out the main findings that support and extend the strength model. These are the phenomena that need to be explained by the strength model and its rivals. In short, these are the facts to be explained.

2.1 Basic Ego Depletion Effects

The first studies in support of strength or energy depletion used a wide variety of procedures in a common research design. Participants performed two separate, independent tasks, one after another. In the crucial condition, both required self-regulation. Tasks have included the Stroop color-word task, the cold pressor (holding one's arm in ice water), stifling emotions while watching emotionally evocative films, suppressing thoughts, persevering in the face of frustration or boredom, writing or typing under various constraints, and forming and then breaking a habit. The typical finding was that performance on the second task suffered as a result of the first, which suggested that some kind of limited resource had been expended and depleted by the first task, leaving less for the second (Baumeister et al., 1998; Muraven, Tice, & Baumeister, 1998; Schmeichel, 2007). A meta-analysis confirmed that these effects are robust and well replicated (Hagger, Wood, Stiff, & Chatzisarantis, 2010).[a]

One general effect of depletion has been to increase a range of impulsive, disinhibited behaviors. Depletion has been shown to increase aggression (DeWall, Baumeister, Stillman, & Gailliot, 2007) and sexual (mis)behavior (Gailliot & Baumeister, 2007). Depleted people make more impulsive purchases and are willing to spend more money for the same goods, as compared to nondepleted persons (Vohs & Faber, 2007). Depleted dieters eat more candy, cookies, and other snack foods (Vohs & Heatherton, 2000). People with alcohol problems consume more alcohol when depleted (Muraven, Collins, & Neinhaus, 2002). More broadly, depletion weakens compliance

[a] Using novel statistical techniques, Carter and Mccullough (2013) reanalyzed the data from Hagger et al. (2010) and argued that the true effect size for ego depletion may be zero; the hundred or so positive findings reported by Hagger et al. (2010) they ascribe to capitalizing on chance. We find this implausible. For one thing, there has been at least another hundred confirmatory findings since Hagger et al.'s meta-analysis, and capitalizing on chance would suggest that those would evaporate. For another, if the true effect size were zero, chance outcomes should lead to equal numbers of findings in both directions: Depletion should improve subsequent performance as often as it impairs it. Such findings of facilitation by depletion would likely be high priority publications. The fact that such a robust pattern is not seen renders Carter and McCullough's conclusion highly dubious.

with social norms for proper behavior, at least when people have impulses to violate those norms. Gailliot, Gitter, Baker, and Baumeister (2012) found that depleted persons were more likely than others to take ethical risks, to use curse words, and to ignore or disobey specific instructions (eg, to refrain from talking). Put simply, depletion inhibits inhibition.

Automatic processes continue to operate in the depleted state. For example, Schmeichel, Vohs, and Baumeister (2003) showed that intellectual performance deteriorated unevenly. That is, depletion impaired effortful and high-level processes such as logical reasoning, extrapolation, and making inferences based on reading comprehension. Meanwhile, though, depletion had no significant effects on simpler intellectual processes, such as rote memorization and accessing general knowledge.

Indeed, there is some evidence that automatic processes may have a stronger effect during depletion than during normal functioning, possibly because the weakness of top-down control allows more bottom-up automatic phenomena to execute without restraint or inhibition. Hofmann, Rauch, and Gawronski (2007) showed that automatic attitudes about candy predicted how much candy people ate when they were depleted, whereas their conscious attitudes about dieting were irrelevant. In contrast, when people were not depleted, their conscious attitudes guided their actions and the implicit ones were irrelevant. In a similar vein, people with insecure attachment styles could fit their self-disclosure patterns to socially appropriate norms when not depleted, but they reverted to their automatic tendencies when depleted: Depletion made avoidant people eschew intimate self-disclosure and made anxiously attached persons eager for it (Vohs, Baumeister, & Ciarocco, 2005).

It would be rash to argue that no automatic processes deplete. In fact, some recent evidence indicates that automatic emotion regulation (nonconscious, nondeliberate processes that alter emotional states, such as damping negative affect) can be depleting (Pu, Schmeichel, & Demaree, 2010). It may be specifically the inhibiting or overriding aspect of self-control, rather than its conscious, deliberate nature, that is depleting. What consumes energy, in other words, is blocking another response. Further evidence about the depleting nature of automatic regulation would be highly informative, however. Likewise, it would be useful to know whether conscious, deliberate processes that do not require blocking a response (eg, "flow") deplete or not.

The relaxation of inhibitory control during depletion and the resultant increase in influence of automatic responses moderate other well-established phenomena. In particular, prejudice is often restrained by self-regulatory

effort, so that depleted persons make more prejudicial judgments and statements than other people (Muraven, 2008). The effect of depletion on vulnerability to automatic, intrusive responses is also evident in an increase in thoughts of death (Gailliot, Schmeichel, & Baumeister, 2006). Normally people manage to keep such disturbing thoughts at bay, but during the depleted state, thoughts about death become more prominent and disturbing in the conscious mind. Highly self-aggrandizing thoughts are often inhibited in accordance with social norms favoring modesty, but automatic egotism emerges when self-regulatory resources are depleted or otherwise preoccupied (Paulhus & Levitt, 1987; Vohs et al., 2005).

Similarly, several investigations have shown that depletion intensifies the detrimental effects of performance anxiety. Test anxiety is a set of troublesome thoughts and feelings that people typically manage to inhibit, especially when taking tests. Bertrams, Englert, Dickhäuser, and Baumeister (2013) showed that anxious thoughts intruded and impaired test-taking performance when participants were depleted—but had no effect on nondepleted control participants, who were able to perform fine despite test anxiety. Englert and Bertrams (2013) found that performance on a perceptual-motor coordination task was determined by participants' anxiety levels in the depletion condition but not in the nondepletion condition. Similar patterns were found for throwing darts and making basketball free throws (Englert & Bertrams, 2012). Thus, depletion weakens the ability to shut out intrusive, disruptive thoughts.

Ego depletion impairs other sorts of task performance too. As compared to nondepleted controls, depleted participants have been shown to give up more readily on difficult tasks (Baumeister et al., 1998) and to perform worse on tasks invoking a speed-accuracy tradeoff (DeWall, Baumeister, Mead, & Vohs, 2011). Performance requiring physical stamina or pain tolerance is also impaired (Muraven et al., 1998; Vohs et al., 2008).

Common to all of these effects is a reduction in top-down control. Under normal circumstances (ie, when resources are replete), the mind can apparently maintain central control so as to subdue inappropriate impulses and maintain socially correct behavior. When depletion weakens central control, these impulses are more likely to emerge and to guide behavior.

2.2 What Else Depletes?

If the resource used for self-regulation were exclusively devoted to that, it would already be an important part of the human self, given the extensive

and diverse uses for self-regulatory capacity. But there is no reason to assume that an energy resource would be exclusively reserved for one particular function. More likely, it may be used for other processes as well.

Evidence suggests that the self-regulatory energy resource has several other uses. The first is making decisions. An early study using procedures from cognitive dissonance research showed that people in the high choice condition (ie, those led to regard the decision whether to write a counterattitudinal essay as entirely up to them) were more depleted than those in the low choice condition (Baumeister et al., 1998). Far more extensive and well-rounded evidence was presented by Vohs et al. (2008) and Bruyneel, Dewitte, Vohs, and Warlop (2006), who showed in multiple contexts that making decisions depleted the person and caused a variety of subsequent decrements.

Related work has shown that depletion caused by initial acts of self-control can alter decision making. Depleted persons become subject to irrational bias and become prone to simplistic, extreme decisions rather than more nuanced compromise choices (Pocheptsova, Amir, Dhar, & Baumeister, 2009). Pohl, Erdfelder, Hilbig, Liebke, and Stahlberg (2013) studied the recognition heuristic, in which people rely on the familiarity of a cue, such as a company name, for an irrelevant judgment, such as estimates of companies' profitability (Goldstein & Gigerenzer, 2002). People used this mental shortcut more often when depleted than in other conditions. These findings corroborate the general notion that a need for effort reduction fosters use of simple decision shortcuts. Having to make tradeoffs is one main reason that making decisions causes depletion (Wang, Novemsky, Dhar, & Baumeister, 2010).

The second extension involves passivity versus initiative. The assumption here is that passive or default responses are easy and require little or no energy, whereas actively taking initiative requires the self's executive function and therefore should be depleting. Vohs et al. (2008) first manipulated depletion and then sat participants at a computer that supposedly would administer the next part of the experiment, but in fact as soon as the experimenter left the room the computer went to static-filled screen and remained inert. Depleted participants sat over almost 50% longer staring at the apparently malfunctioning computer before taking remedial action to get help. Vonasch, Vohs, Baumeister, Pocheptsova, and Dhar (2016) found that depletion caused an increase in various passive behaviors. One study manipulated ease of getting food by serving peanuts either in or not in shells. Without shells, hungry persons ate more nuts when depleted than when not

depleted. With peanuts in the shells, the pattern reversed. Thus, depletion produces both disinhibition and lazy passivity.

Depletion caused by making choices can also lead to passivity in subsequent decisions. Levav, Heitmann, Herrmann, and Iyengar (2010) found that as people went through the many decisions required to purchase a complex product, such as a self-configured car or a bespoke suit, they increasingly chose the standard or default option. The initiative to depart from the default option apparently dwindled as one became depleted by making other decisions.

Planning may also draw on the same limited resource. Like self-regulation and rational choice, planning is an advanced form of volition that depends on deliberate control of action, use of ideas to guide behavior, and meaningful integration of acts and events across time. Planning was linked to ego depletion in a pair of experiments by Webb and Sheeran (2003). They showed that implementation intentions, which are simple plans in the form of "If X, then I do Y" (Gollwitzer, 1999), counteracted ego depletion. They had participants make implementation intentions to facilitate performance on the Stroop task. After they performed the Stroop task with such plans, they showed less depletion on a subsequent task. In a second study, when participants were depleted by a different task, the implementation intentions helped them sustain good performance on the Stroop task. Thus, having a good plan reduces the need to make choices when one is faced with questions of how to respond. There is however at present no clear evidence that planning causes depletion.

Habits are largely automatic responses, which one sometimes uses self-control to break or change. When people are depleted, their behavior conforms more to habits, as compared to a nondepleted state (Neal, Wood, & Drolet, 2013). Both good and bad habits are facilitated by depletion, and so it is all the more important to have good habits that are conducive to making progress toward one's goals.

Most work has focused on how trying to control or alter one's responses causes depletion. Some recent work has however begun to show other factors contributing to depletion. Alquist, Baumeister, and Tice (2016) found that going through uncertain situations is depleting, in the sense that after exposure to uncertainty, self-regulatory performance was impaired in ways resembling the usual depletion effects. In one study, participants had to solve problems that were unclear as to which instruction to follow. In several others, participants were uncertain as to whether they would later have to make a speech or not. These participants later exhibited self-regulatory

deficits. In fact, not knowing whether one would have to give a speech (which is generally an aversive, anxiety-producing prospect) caused poorer self-regulation than knowing for certain that one would have to give a speech. Thus, the uncertain possibility of a bad outcome was more depleting than definitely expecting the same bad outcome.

One essential part of self-control is monitoring, which involves keeping track of one's responses as they pertain to a standard. Critcher and Ferguson (2014) found that having to monitor one's responses is depleting. One experiment showed that concealing information about one's sexual orientation during a conversation led to depletion (measured as raters' judgments that participants wrote more impolite responses to an obnoxious e-mail) even though the conversation never veered into one's personal life. This work thus provides some initial evidence that the process of monitoring may itself deplete resources.

2.3 Conservation

Although it was initially tempting to regard ego depletion as a state of impaired brain function caused by the exhaustion of its fuel supply, this simple account quickly proved inadequate. Indeed, the resource would have to be in remarkably short supply if a brief 5-min laboratory task exhausted it.

Work by Muraven and colleagues established that depletion effects are essentially conservation effects (Muraven et al., 2006; Muraven & Slessareva, 2003). That is, the person may have partly depleted some resource during the first act of self-regulation but still has plenty left. Impairments in self-regulatory performance thus reflect the attempt to conserve what remains of the resource, rather than indicating a thoroughgoing exhaustion of the supply. This is analogous to physical energy: the body naturally starts to conserve its energy as soon as physical exertion depletes some of it, even though plenty of energy remains (Abdel-Hamid, 2002).

The fact that depleted people retain sufficient resources to perform at a high level was attested by Muraven and Slessareva (2003), who showed that offering financial or social incentives elicited very good self-regulatory performance even following a depletion manipulation. Thus, although the decrements due to ego depletion have been well documented, people are able to overcome them if sufficiently motivated.

Systematic tests of the conservation hypothesis were provided by Muraven et al. (2006). They showed that people show strong depletion

effects when anticipating further self-regulatory demands later on, indicating that people conserve the limited resource so as to be able to meet those demands. People perform better when not anticipating further demands, presumably because there is less need to conserve current resources. Moreover, conservation was successful: After being depleted by a first task, the worse they performed on a second task (thus presumably conserving in anticipation of further demands), the better they did on a third task.

Similar findings were reported by Graham, Bray, and Ginis (2014), using physical exercise. After a first, depleting task, participants who had been informed of an upcoming (third) challenging task withheld effort on the second task, performing worse than those who were equally depleted but who did not anticipate later demands. Participants even reported greater intent to conserve energy when anticipating another task than when not. In this study, unlike Muraven et al. (2006), the conservation was not apparently effective, as performance on the third task was no better among those who had anticipated it (and therefore conserved) than those who had not. The authors had predicted that conservation would benefit performance, and they speculated that the failure may have been due to switching between cognitive and physical endurance tasks, as well as possibly the impact of extra instructions pertaining to autonomy.

Conservation was also shown by Tyler and Burns (2009). After a demanding task, performance declined, but performance was better among those who were led to believe they were almost finished as compared to those who believed they had another 20 min to work. The implication is that those who believed they had more work to do held back so as to conserve resources.

Using mental heuristics conserves energy. Vonasch and Baumeister (2016) found impaired self-control, consistent with ego depletion, among participants who had been instructed to think carefully while solving complex logic problems. In contrast, participants who did the same problems but under instructions to give quick, gut-feeling answers performed better. Another study in the same investigation found that depleted persons used heuristic styles of problem solving more than nondepleted ones.

These findings underscore the point that depletion is generally partial. The energy available for self-regulation does not get entirely used up, and indeed even ego-depleted people possess ample energy available to enable unimpaired performance. Thus, decrements in self-regulatory performance may represent an inclination to conserve the self's diminished resources rather than an inability to wield further self-control.

2.4 Increasing Strength

One implication of the strength analogy is that it might be possible to increase self-regulatory capacity by exercise. Physical exertion brings tiredness (and impaired capacity and performance) in the short run but improves power and stamina in the long run. The same might apply to self-regulatory strength.

Multiple studies have had people perform arbitrary exercises on self-control and then (after having practiced for a period of time) observed improvement on laboratory tests that involve behaviors quite different from the practiced ones. Muraven, Baumeister, and Tice (1999) had participants build self-control by improving their posture and showed improvements on handgrip stamina. Oaten and Cheng (2006a, 2006b) had participants exercise self-control by improving study habits, improving financial discipline, or adopting a physical exercise program, and these were verified by improved performance on a lab test that measured visual tracking of stimuli despite ongoing distractions.

Several studies have carried this work further to show that building self-control through exercise can help ameliorate problem behaviors. Gailliot, Plant, et al. (2007) showed that people were less depleted by overcoming prejudicial stereotyping if they had completed 2 weeks of exercises of verbal control or, in other studies, exercises requiring substituting the nondominant hand for tasks habitually done with the dominant hand. (The verbal and handedness exercises had nothing to do with stereotypes.) Most remarkably, Muraven (2010) found that 2 weeks of exercises consisting of resisting sweets or performing minor physical exercise doubled participants' success at quitting smoking. Finkel et al. (2009) found that 2 weeks of self-regulatory exercises involving either motor control (eg, using one's nondominant hand to open doors) or verbal control (eg, avoiding abbreviations, not cursing) led to a reduction in inclinations to respond with physical aggression to provoking behavior by intimate relationship partners.

Thus, a number of longitudinal studies have shown significant improvements in self-regulatory capacity as the result of doing exercises in self-control for a couple of weeks or a month. We conclude that performance at self-control can be improved, and the pattern fits that of a domain-general resource. That is, exercising self-regulation of one or two sorts of behaviors causes discernible improvements on seemingly unrelated tasks (that also involve self-regulation).

2.5 Glucose Dynamics

Two papers in 2007 concluded that the energy that gets depleted during self-regulation was indeed closely linked to the body's physical energy supply, namely, glucose levels. Glucose is the body's energy and is carried in the bloodstream to the muscles and organs. There is some dispute as to whether glucose itself enters the brain, but some neurotransmitters are made from it, thus rendering plausible the view of glucose as "brain fuel." Crudely put, this view depicts effects of ego depletion as indicating that the brain is running out of fuel, and so advanced and complex activities such as self-regulation are cut back or shut down.

A literature review by Gailliot and Baumeister (2007) of research in nutrition and physiology linked low blood glucose (or ineffective processing of high levels of blood glucose, as in diabetes) to poor self-control. A series of experiments by Gailliot, Baumeister, et al. (2007) produced three conclusions.

The first conclusion was that blood glucose levels went down from before to after self-regulation. Since then, the first conclusion has come under critical scrutiny, including from our own laboratories, whose recent findings have not replicated the drop in blood glucose even when finding significant glucose effects involving self-regulation. For example, Ainsworth, Baumeister, and Boroshuk (2016) found glucose went up in some cases of moderate depletion, although more severe depletion based on multiple tasks did produce reliable drops in blood glucose levels. Even in the original Gailliot, Baumeister, et al. (2007) paper, support for the drop in blood glucose was weaker than for the other findings and may have benefited from a fortuitous control condition. At present, therefore, the best educated guess is that the conclusion was wrong, and blood glucose levels do not reliably drop as a result of a brief self-regulatory effort. It may be that self-regulation consumes glucose but sometimes the person makes more glucose available from the body's stores. The allocation of more resource from stores would thus sometimes offset the drop in available glucose, producing the inconsistent results. Limited evidence suggests that more extensive exertions would reduce blood glucose, but more research is needed.

Although the notion of the brain running out of fuel and therefore shutting down is not a viable explanation of depletion effects, it does appear that the brain uses extra glucose when working hard. Studies with positron emission tomography have confirmed that frontal regions of the brain increase their metabolism of glucose when involved in continuous performance

(Buchsbaum et al., 1990), that improvement in effortful performance is correlated with a rise in glucose metabolizing (Siegel, Nuechterlein, Abel, Wu, & Buchsbaum, 1995), and that as skills become automatic through practice, the consumption of glucose declines (Haier, Siegel, Tang, Abel, & Buchsbaum, 1992).

The second conclusion was that low levels of blood glucose were linked to poor performance on laboratory tests of self-control. At present, that seems solid. Extensive research in nutrition and related fields already had linked low blood glucose levels to a variety of behaviors indicative of poor self-control, including deviant and criminal activity (for review, see Gailliot & Baumeister, 2007). For example, diabetics (who have problems metabolizing glucose) are known to be highly distractible, especially when glucose levels are low (eg, Zhao & Liu, 1999), and also to have problems with emotion control. Adolescent criminals and delinquents have poorer glucose tolerance than peers. Impulsivity is high among people with poor glucose tolerance. The experiments by Gailliot, Baumeister, et al. (2007) also found that performance on self-control tests varied with blood glucose levels. Hence, at present, it seems fair to conclude that low levels of glucose in the blood are generally linked to poor self-control. Recent work by Bushman, Dewall, Pond, and Hanus (2014) has even shown that daily fluctuations in glucose level among married couples were linked to proxy measures of spousal aggression. That is, low levels of blood glucose weakened what is normally a strong inhibition against physical maltreatment of one's husband or wife.

The third conclusion was that getting a dose of glucose counteracted depletion effects. This also continues to work well, in our laboratories and in others. Early work showed, for example, that children coped better with a frustrating (impossible) task if they had received a dose of glucose (Benton, Brett, & Brain, 1987). Getting a dose of glucose has been shown to restore the self-regulatory performance of depleted persons to high levels (equivalent to nondepleted persons). A dose of glucose generally has no effect on nondepleted persons, though we might expect some effects to show up occasionally (insofar as many research samples include people who are already somewhat depleted when they arrive at the lab). The finding that glucose restores self-regulatory performance among people who have previously exerted self-regulation has been replicated with helpfulness (Gailliot, Baumeister, et al., 2007), irrational biases in decision making (Masicampo & Baumeister, 2008), depleting effects of uncertainty (Alquist et al., 2016), deducing rules for predicting events (McMahon &

Scheel, 2010), correctly solving tricky word and number problems (Vonasch & Baumeister, 2016), and discounting future outcomes in decision making (Wang & Dvorak, 2010). Perhaps most dramatically, a field study found that judges' parole decisions became increasingly cautious and harsh (ie, declining to grant parole) as the day wore on, presumably as the judges became increasingly depleted from making many such decisions (replicating Vohs et al., 2008). This trend was sharply reversed at two points in the day, corresponding to glucose inputs, namely, right after the mid-morning snack and again after lunch (Danziger, Levav, & Avnaim-Pesso, 2011).

2.6 Overcoming Depletion

By this point, multiple studies have confirmed that certain manipulations can eliminate and possibly reverse the effects of depletion. Often these findings have tempted authors to conclude that the energy model is wrong and the true mediator is intimately tied to what they have manipulated. If the behavioral consequences of ego depletion can be reversed by certain thoughts, feelings, or symbols, does that mean that no resource was actually depleted? Hence we shall revisit several of these findings in the sections dealing with challenges to the theory. For now, however, it is useful to have an overview grasp of what has been shown to nullify the detrimental after-effects of self-regulatory exertion. These provide further evidence that the capacity for self-regulation is not exhausted or devastated by a brief laboratory exercise. Rather, plenty of capacity remains despite depletion, and assorted procedures or interventions can access it so as to eliminate the usual decrements associated with depletion.

Essentially, the design for these studies involves administering the usual two-task sequence and then interpolating another manipulation in between them. For example, Tice, Baumeister, Shmueli, and Muraven (2007) provided multiple replications of the usual depletion effect but also showed that the effect disappeared among participants in whom positive affect was induced following the depleting task. Receiving a small gift or watching a comedy video thus counteracted depletion. Although this work was done based on the hypothesis that positive emotion might actually replenish the depleted resource, the procedures were unable to distinguish that conclusion from the (more plausible) hypothesis that positive emotion simply encouraged people to continue exerting self-control despite being somewhat depleted. In a similar vein, Shmueli and Prochaska (2012) found that smokers increased their smoking when depleted (by resisting tempting food

desserts) but that this effect was eliminated if they watched a funny video. People were less depleted to the extent they found the process enjoyable, as seen in multiple experiments (Polman & Vohs, in press; Vohs et al., 2008). Ren, Hu, Zhang, and Huang (2010) provided evidence that even implicit positive emotion helps offset the effects of depletion.

Other procedures have likewise overcome depletion effects. Having people read words related to religion, such as *God* or *divine*, both neutralized the depletion effect and even improved baseline self-regulatory performance among nondepleted persons (Rounding, Lee, Jacobson, & Ji, 2012). Likewise, praying prior to exercising self-control (stifling emotional reactions to a comedy video) reduced errors on a subsequent Stroop color-naming task, which otherwise increased following the depleting emotion suppression task (Friese & Wänke, 2014).

Several manipulations that make the self salient have been shown to offset depletion effects. Schmeichel and Vohs (2009) found that instructing people to think of their most cherished values (ie, engage in self-affirmation) eliminated the depletion effect. Along similar lines, Wan and Sternthal (2008) showed that getting people to keep their standards in mind reduced the depletion effect. Alberts, Martijn, and De Vries (2011) showed that depleted participants who then completed a phrase-making task performed better if the phrases contained the word "I" than if the phrases did not refer to the self. Thus, affirming the self, reflecting on the self's standards, or simply thinking of the self can overcome depletion.

Assigning participants to a position of power and leadership caused improvements in self-regulation, including a complete elimination of depletion effects (DeWall et al., 2011). However, when a surprise additional test was administered later, these participants showed very substantially impaired performance, indicating that the ostensible immunity to depletion was temporary and limited. These findings also fit the view that what happens when situational incentives overcome depletion is that the person continues to expend the diminished resource, thereby depleting it further—as opposed to indicating that the manipulation replenished the resource or indicating that nothing was actually depleted.

Assorted findings fit the view that activating agentic responses can overcome depletion. If depletion makes control and initiative weak because the person conserves the diminished resource, then factors that prompt the person to continue exerting control and initiative can overcome its effects, at least temporarily. Encouraging people to take responsibility and feel autonomous can overcome depletion effects (Graham et al., 2014; Muraven,

Gagné, & Rosman, 2008). Depletion effects on performance were overcome by Martijn et al. (2007), by providing depleted participants with an inspiring story of an athlete who battled setbacks to become a world record holder. More direct evidence that agency cues can improve performance despite ego depletion was provided by Alberts, Martijn, Greb, Merckelbach, and Vries (2007). They found that after a difficult puzzle task, compared to an easy one, physical stamina on a handgrip exerciser was worse unless participants had earlier performed a verbal task that led them to make phrases that related to high persistence, such as "He keeps going." A second experiment counteracted depletion by exposing participants to a picture of a man in a business suit and the words "you can do it."

Some depletion effects may be mediated by shifts in thinking. Low level construals involve thinking in terms of specific, local, and peripheral features of the situation, whereas high level construals involve superordinate, global, and central features, including long time spans. We have already emphasized that ego depletion reduces top-down control, and that can be manifested by a shift toward low-level construal. Consistent with that view, recent work has found that depleted persons shift downward toward low-level construals (Bruyneel & Dewitte, 2012; Wan & Agrawal, 2011). People in a depleted state feel that time is moving slowly, which is consistent with a lower level perspective that emphasizes specifics (Vohs & Schmeichel, 2003). Adopting a low-level construal would render people vulnerable to situational cues, impulses, and the like. Depletion can therefore be overcome by encouraging depleted persons to adopt a high construal level. Consistent with that hypothesis, Fujita, Trope, Liberman, and Levin-Sagi (2006) showed that inducing high-level construals benefited self-regulation among both depleted and nondepleted persons.

Cues that remind people of money have been shown to activate agentic responses and goal pursuit (Vohs, Mead, & Goode, 2006), even when the money is irrelevant and in no way is an incentive for good performance. Being exposed to money overcomes depletion effects (Boucher & Kofos, 2012). Job, Dweck, and Walton (2010; also Martijn, Tenbült, Merckelbach, Dreezens, & de Vries, 2002) showed that convincing people that their willpower was unlimited eliminated the depletion effect, a finding to which we shall return in the section on challenges to the theory.

Last, depletion can be offset by relaxing or taking a break from using self-control. Tyler and Burns (2009) had participants in the depletion condition perform the difficult task of standing on one leg and counting down from 2000 by sevens, whereas others stood on both legs and counted down by

fives. Then they worked on filler questionnaires for 1, 3, or 10 min. The 10-min break enabled the depleted participants to perform just as well on a handgrip task as participants in the nondepletion condition. Unlike some of the other antidotes just reviewed, rest and glucose might actually permit replenishment, whereas influences such as money cues and feelings of high power might simply encourage people to expend more energy and thereby deplete themselves more.

2.7 Mild vs Severe Depletion

If the strength model is correct and a limited resource is expended during self-regulation, then one would expect there to be varying degrees of depletion, corresponding to how much of the resource has been consumed. To be sure, the conservation model substantially reduces the expected size of dose–response relationships. The conservation model assumes that people have ample stores of energy, so that depletion effects are about whether to conserve or expend what remains, rather than indicating that the brain is unable to function for lack of fuel. A greater degree of depletion would not necessarily prevent the person from self-regulating just as effectively as after a lesser degree. Still, to pursue the analogy to physical energy and tiredness, one would expect there to be some differences between slight depletion (where effects first become noticeable) and extensive, substantial depletion.

Recent work has begun to distinguish different degrees of depletion, which seem to produce some qualitatively different effects. The general procedure distinguishes mild depletion, typically created by having participants perform one self-control task for a few minutes, from more severe depletion, which is accomplished with a (longer) series of several depleting tasks. The first effort of this sort was by Vohs et al. (2008), who showed that the depleting effects of making choices depended on the pleasantness of the choices when only a relatively few were made (4 min)—but those effects occurred regardless of pleasantness when more choices had to be made (12 min). Choi and Fishbach (2011) found that depletion effects were not seen after participants made only one choice but emerged significantly after they made seven choices.

Extreme states of depletion are not typically achieved with laboratory procedures, for ethical and practical reasons. Work on low-SES teens, whose use of good self-control is presumably quite challenging given the circumstances (Brody et al., 2013; Miller et al., 2015), suggests physical costs of sustained, intense self-control exertion.

Several of the other studies of this type have been conducted to respond to evidence that various manipulations can eliminate and sometimes even reverse depletion effects. Most of that evidence works with mild depletion. We know of no findings overcoming severe depletion. In fact, some follow-ups have found that severe depletion is much harder to eliminate or reverse than mild depletion (Graham et al., 2014; Muraven et al., 2008; Vohs et al., 2008; Vohs, Baumeister, & Schmeichel, 2013).

2.8 Physiological Processes and Stress

A concept that often is thought to be similar to self-regulation is stress. In stress, the body prepares itself to fight or flee by quickening heart rate and getting the large muscles ready for action. Work by Segerstrom and colleagues found that the body's response to self-regulatory demands is quite different than for stress. During self-regulation, heart rate slows, heart rate variability goes up (which is a sign that executive functioning is being used), mood is not changed appreciably, and the cardiovascular and immune systems quiet (for a review, see Segerstrom, Hardy, Evans, & Winters, 2012). Stress, conversely, raises heart rate, lowers heart rate variability, and worsens mood (Segerstrom & Solberg Nes, 2007). To be sure, some responses to stress involve executive control, in which case one would expect the bodily processes to be similar. In any case, the fact that energy shifts from some organs toward others during stress and self-regulation is consistent with a limited-energy model (and explains why a central governor has to be central).

Chronic pain requires frequent self-regulation, and empirical work has shown that people suffering from it seem to be chronically depleted. Solberg Nes, Carlson, Crofford, de Leeuw, and Segerstrom (2010) found that exposing patients with severe pain disorders and nondisordered participants to an attention control task that was taxing (depletion condition) or not very taxing (nondepletion condition) led to differences in persistence on a subsequent anagram task. The only group to perform differently than the rest was the nonpatient, nondepleted group. The chronic pain patients performed poorly, regardless of prior exertion of self-control, indicating that they may lack self-regulatory resources on a consistent basis (see also Solberg Nes, Roach, & Segerstrom, 2009).

The body prioritizes which organs get more resources depending on the demands from the environment. As mentioned, Segerstrom and colleagues have documented the changes in heart rate from depletion, and recent work indicates that depletion also alters the way that the liver metabolizes alcohol

(Eisenlohr-Moul, Fillmore, & Segerstrom, 2012). High and low self-control men consumed a small dose of alcohol and then performed a series of tasks that required self-regulation or did not. Even 90 min after having imbibed, low self-control men who were depleted had higher blood alcohol content than did others. When people are depleted, the liver reduces its work, quite possibly to save energy. The resulting fact that a person can enjoy intoxication for a longer period of time could in principle enhance the appeal of alcohol to some people (such as those low in self-control).

Behavioral passivity is one of the outcomes of depletion (eg, Baumeister et al., 1998; Vonasch et al., 2016). Signs of the brain becoming more passive and less in control of its thoughts also have been found after depletion. Sripada, Kessler, and Jonides (2014) manipulated depletion and measured signs of activity coming from the brain's default network, which produces task-irrelevant thoughts and mind-wandering. Depletion allows the default network to become more active than otherwise, which might provide insights as to why depletion leads to impairments in mental control.

A literature review by Gailliot, Hildebrandt, Eckel, and Baumeister (2010) concluded that premenstrual syndrome likely involves self-regulation failure brought on by lack of glucose. During the luteal phase of the menstrual cycle, the female body devotes more energy than usual to its reproductive activities, leaving less available for self-regulation.

2.9 Subjective Feelings

Although behavioral effects of ego depletion have been widely documented in many forms, subjective effects have been elusive. That is, self-report measures fail to indicate much difference between ego depletion and the non-depleted normal state. The meta-analysis by Hagger et al. (2010) found only a slight increase in negative affect, which may reflect the simple fact that many depletion procedures are slightly unpleasant. The effect was too small to reach significance in most studies and was only found with the greatly enhanced statistical power that meta-analysis affords. The meta-analysis likewise found that depletion produced an overall increase in self-reports of fatigue, but again these were very weak effects and usually not significant with typical samples.

To be sure, depletion increases vulnerability to negative emotion, presumably because defenses are weakened. We already mentioned the findings that thoughts of death intrude more than normally when people are depleted (Gailliot et al., 2006).

More recent work has found intrusion of general negative affect to increase among depleted people—in contrast to cognitive load manipulations, and thus contrary to a frequent assumption that cognitive load and depletion are largely the same. Maranges et al. (2016) found that negative feelings arising from seeing unpleasant pictures increased among depleted persons but not among cognitively loaded ones. In another study, ego depletion increased the tendency to group items based on negative emotional associations (but not positive), whereas cognitive load had no such effect. Even the pain of holding one's hand in ice water differed. Cognitive load reduced pain and therefore lengthening submersion times. In contrast, ego depletion increased pain and reduced submersion times. Cognitive load and ego depletion are thus different in important ways. Moreover, the effects do not fit the view that ego depletion causes negative affect by itself. Rather, it increases vulnerability (presumably by reducing defenses) to cues that evoke negative emotion.

Although there appears to be no clear subjective state that constitutes a signature feeling of depletion, there is some evidence that depletion brings an intensification of a broad range of emotions, moods, and desires. Vohs et al. (2016) found that depleted participants reported stronger reactions to both positive and negative stimuli, as well as having stronger desires under similar circumstances, than nondepleted controls (see also Marcora, Staiano, & Manning, 2009).

Exactly why depletion intensifies feelings is not fully clear. Normal psychological processing of affectively potent stimuli may reduce their impact (Wilson & Gilbert, 2008). Depletion may curtail some of this elaborative processing, thereby failing to reduce the affective impact of the stimuli. Indeed, such a pattern could constitute a general inhibition of all feelings and reactions, which again might lose effectiveness in the depleted state. There is also some evidence that there is a tradeoff between executive and evaluative processes in the brain, so that as executive processes are curtailed by depletion, evaluative ones would increase.

2.10 Positive Effects of Depletion

Most of the work reviewed thus far has painted a negative picture of the depleted person. Overeating, overspending, prejudice, aggression, and passivity are not the kinds of traits that are good for the self or society. Nonetheless, research has shown that depletion can lead to healthier and better behaviors than a nondepleted state, which suggests that the process by which

depletion leads to subsequent responses might be more nuanced than initially thought. Much of the work reviewed next suggests that a key might be the presence of a strong situational cue or well-established routines.

Some findings indicate that depletion is not as much about giving into temptations as it is about letting a habit run its course. Neal et al. (2013) found that habit strength (ie, how frequently and consistently participants perform a behavior) was key to predicting behavior after depletion. This suggests that depleted people have difficulty shifting away from defaults, a conclusion backed by work showing that depletion can make people more generous than otherwise. In a reversal of findings showing that depleted people are greedy or selfish (eg, Halali, Bereby-Meyer, & Ockenfels, 2013), Banker, Ainsworth, Baumeister, Ariely, and Vohs (2016) found that depletion made people either more or less generous in a dictator game, depending on situational cues (ie, the anchoring starting point for the allocation). In other words, depletion made people more susceptible to situational cues, and when the cues supported prosocial generosity and fairness, depletion increased that sort of behavior.

Not being able to shift away from one's typical responses can be advantageous at times. Apfelbaum and Sommers (2009) found that depleted participants enjoyed a conversation with a black person more and were more likely to have discussed the topic of racial diversity, as compared to nondepleted participants. Black coders who listened to audiotapes of participants rated depleted participants in the interracial condition as being less prejudiced than nondepleted participants—which is notable when considered in light of consistent findings indicating that depletion increases prejudicial thoughts and actions (eg, Muraven, 2008). The findings presumably indicate that when white people speak with Black ones, the whites monitor and regulate their behavior to avoid all possible offense, and this effort renders the interaction awkward and anxious. When the white folks are depleted, they cease to do this, and their more relaxed manner impresses their interaction partners as being more genuine and personable.

Work on healthy behaviors and charitable giving found that these behaviors rose when depleted people were exposed to strong situational norms promoting the behavior. Salmon, Fennis, de Ridder, Adriaanse, and de Vet (2014) told participants that healthy foods were popular with their peers, which led depleted participants to choose more of them than those who were not depleted. Fennis, Janssen, and Vohs (2009) showed that depletion could increase donations of time and money to worthy causes—but only in

combination with prosocial cues. Depletion alone did not increase prosocial behavior. The implication is, once again, that depletion reduces top-down control, so that behavior is guided increasingly by external cues via automatic processes.

3. THEORETICAL CHALLENGES AND COMPETING MODELS

This section addresses the major theoretical disputes and problems that have cropped up regarding the theory. We shall present each challenge and evaluate its potential for discrediting, replacing, revising, and/or augmenting the basic theory. Some of these have already changed our own thinking.

3.1 Resource Allocation

Several writers have questioned the original notion that depletion is a matter of exhaustion of limited resources so that self-regulation becomes impossible because of a lack of fuel. The findings by Muraven and Slessareva (2003) already showed that people could overcome depletion when presented with a motivational incentive to do well (such as when getting paid or thinking that their efforts can benefit others). Thus, obviously, people retain the capacity for self-control while in the state of ego depletion. Originally, this was understood as a matter of accessing backup energy supplies. Possibly the glucose in the bloodstream was used for self-regulation, and when that was depleted self-regulation would be impaired—unless there was a compelling reason to access the backup stores.

A more radical reformulation was however proposed by Beedie and Lane (2012). Their view discarded the importance of using up glucose in the bloodstream and proposed instead that self-regulation is always fueled from the body's energy stores, which are extensive, especially for well-fed members of modern civilizations. The behavioral effects of the depleted state, reflecting poor self-control, occur because the body refuses to allocate sufficient energy to regulate itself effectively. Put another way, they proposed that the idea of depletion as being out of fuel was wrong: There is still plenty of fuel. Behavioral outcomes depend on whether one allocates energy to this or that activity. Beedie and Lane (2012) suggested that the body usually (though not always) has sufficient fuel to support brain activity, including self-regulation, and it will do so as long as that brain activity is consistent with the person's motivational priorities.

3.1.1 Evidence

In our view, the notion of selective allocation fits the currently available evidence better than the original notion of being out of fuel. The original evidence for the view that blood glucose levels drop as a result of self-regulation was a pair of studies by Gailliot, Baumeister, et al. (2007). Their data were not strong. Some subsequent studies have found declines (Dvorak & Simons, 2009) but not enough to be convincing. Our own laboratory work has not consistently replicated the drop. For example, a recent study found no change in glucose after one depleting task, although glucose levels did drop significantly after several depleting tasks, suggesting that severe depletion might be needed to produce a discernible drop (Ainsworth et al., 2016). Meanwhile, evidence has continued to accumulate that people can perform well despite depletion when sufficiently motivated, starting with studies by Muraven and Slessareva (2003), in which cash incentives and social motivations caused people to perform well despite depletion. All these findings suggest that self-regulation is not powered mainly or exclusively out of glucose in the bloodstream.

3.1.2 Compatibility

The notion of selective allocation can be taken either as a compatible complement to resource-depletion theory or as a replacement for it. To be the latter, it would have to assert that the body has essentially unlimited resources of energy and for all practical purposes can always allocate more. Beedie and Lane (2012) seemed to favor this view and suggested that depletion effects only occur because research participants appraise the task as inconsistent with their personal priorities.

All of this does raise a puzzle, however: Why would one allocate a resource sparingly if it were unlimited? Why would priorities change so dramatically as a result of exerting self-control? After all, a truly unlimited resource does not have to be allocated judiciously. The very fact of selective allocation implies that the resource is limited.

The allocation notion is thus highly compatible with a limited resource model, and indeed it may be best understood in that combination. The body may have extensive reserves of glucose-based energy, but it is presumably also designed to conserve those, because they are limited (and presumably because running out or even running low would expose one to severe risks and disadvantages). Beedie and Lane (2012) seem to concur: "In simple terms, the body is conserving its resources" (p. 150). Although they say that only under somewhat rare and extreme circumstances would the body

actually run out of energy, the danger of this happening may well underpin the design of a system that conserves energy and allocates it judiciously.

It has long been thought that the brain's energy consumption is essentially stable. Recent work, however, has indicated that it does fluctuate, in particular increasing at times of heavy cognitive demand (Göbel, Oltmanns, & Chung, 2013; Peters et al., 2004). The increase may not show up in aggregate measures of energy use because the body strives to keep overall use constant, so as not to deplete stores. In practice, this means that when the brain needs more energy, less is allocated to other functions such as heart and liver. (That presumably explains evidence that heart rate and liver function drop as a result of self-regulatory exertion; Eisenlohr-Moul et al., 2012; Göbel et al., 2013; Segerstrom et al., 2012.) As these other functions cannot be left underpowered for long, the central governor system will try to avoid long periods of elevated brain activity—hence, perhaps, depletion effects.

Moreover, in evolutionary history, the limits and constraints were presumably much more pressing than in modern life, as prehistoric humans could not rely on food being always available to restore any energy that had been expended (unlike in many modern countries). The danger of having inadequate energy could have been substantial, especially insofar as hunting, foraging, and reproduction require energy. As noted above, conserving energy for the immune system was vital for sustaining life. Hence there may be deeply ingrained tendencies to conserve energy, even among well-fed modern citizens who will never run out.

3.1.3 Conclusion

Not only is allocation compatible with a limited resource account, but it hardly makes sense without it. Therefore, we think the allocation view should be seen as part of the next generation of resource-depletion theory rather than as a rival to it. The conservation evidence is very consistent with this view, insofar as it shows that people save their self-control resources for future demands—something that would not be necessary with an unlimited resource. The analogy to physical exertion is again apt: Ordinary people hardly ever get to the point of complete physical exhaustion, but they quickly start to conserve energy when just slightly tired from some moderate exertions.

3.2 Implicit Fulfilled Contract

In our experience, the most frequently raised alternative explanation for depletion effects invokes the notion of an implicit contract. In the typical experiment, the first (depleting) task requires effort or sacrifice, or at least

something mildly unpleasant. The participant expects the research project to involve something of that nature, but the first task fulfills that expectation and exhausts the participant's willingness to exert or sacrifice. The drop in performance on the second task is then explained by saying that participants feel they have discharged their obligation and lack reasons or motivation to do any more, beyond the bare minimum. For example, the standard finding of reduced persistence on the second task would indicate that participants feel they have already done enough work for the experiment and want to finish up and go home. In this account, there is no need to postulate any depletion of an energy resource—all that has disappeared is the good-natured willingness to put forth effort as a dutiful participant. This view figures in several formal challenges (see below), but it is often raised on its own, and so it merits consideration by itself.

3.2.1 Compatibility

Some reduction in willingness to work for the experimenter could occur precisely because the first task depleted an energy resource. Thus, the reduction in willingness to exert could be fully compatible with a resource-depletion account.

3.2.2 Evidence

Abundant evidence contradicts the implicit contract view. It was tested meta-analytically by Hagger et al. (2010). There was no moderation of the depletion effect as a function of whether the depleting conditions and outcome measure were said to be two separate studies. Likewise, there was no effect for whether the two tasks were administered by different experimenters. Thus even with the greater statistical power gained from combining experiments, the implicit contract received no support.

Several findings speak quite strongly against the implicit contract. Baumeister et al. (1998) found that depleted participants would sit longer watching a boring movie if ending the film required an active response. This finding is the opposite of what participants would do if their goal were to finish the experiment and leave, as the implicit contract model proposes.

Most evidence for depletion effects comes from laboratory studies (hence the argument about having fulfilled one's research obligation). Implicit contracts are much harder to invoke to explain behaviors outside the laboratory. In a field study, Hofmann, Vohs, and Baumeister (2012) showed that the more often people resisted various desires throughout the day, the less

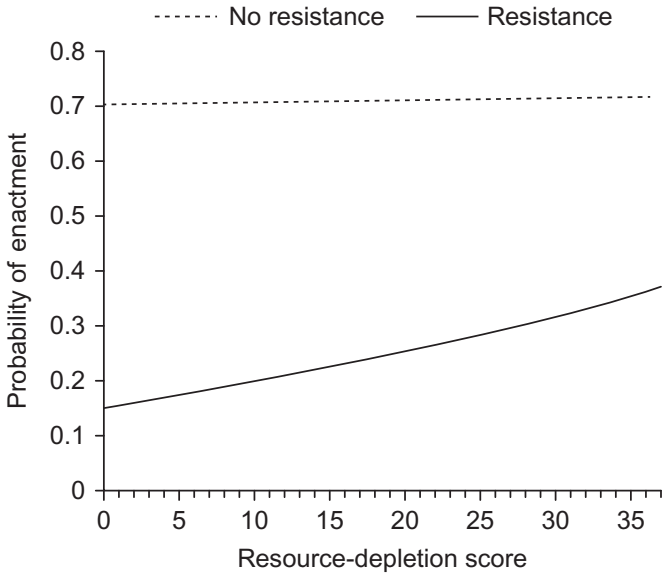

Fig. 1 Probability with which participants enacted a given desire as a function of resource-depletion score, separately for occasions on which people did and did not attempt to resist the desire. The resource-depletion score reflects the number of previous resistance attempts (regardless of desire content) on the same day. Previous resistance attempts were weighted such that more recent resistance attempts received more weight than more temporally distant resistance attempts. *Reprinted from Hofmann, W., Vohs, K. D., & Baumeister, R. F. (2012). What people desire, feel conflicted about, and try to resist in everyday life.* Psychological Science, 23, *582–588. http://dx.doi.org/10.1177/0956797612437426, Psychological Science.*

successful their subsequent resistance (Fig. 1). No implicit contract with an experimenter could explain that finding. In a similar vein, Levav et al. (2010) found that as consumers made many decisions about buying a car or a custom-tailored suit, they became increasingly prone to take the default or standard option. Again, this cannot be explained by any sort of implicit contract.

Meanwhile, we find no evidence of a change in attitude toward the experimenter or a reduced willingness to comply with further research procedures as a function of depletion manipulation. Meanwhile, depletion produces plenty of effects that do not fit into an implicit contract framework, such as worse speed-accuracy tradeoffs (Englert & Bertrams, 2013), good and bad habits getting stronger (Neal et al., 2013), preferring status quo options (Polman & Vohs, in press), and healthier and more charitable behaviors increasing with prosocial cues (Fennis et al., 2009; Salmon et al., 2014).

In short, no evidence directly supports the implicit contract idea, and much evidence specifically contradicts it.

3.3 Motivation and Attention

One important challenge has proposed that motivation and attention explain depletion effects (Inzlicht & Schmeichel, 2012). Such a challenge is highly relevant, because it could potentially get rid of the troublesome innovation of invoking energy and could instead replace it with psychology's more conventional explanatory tools of attention and motivation. Thus, potentially, it could argue that self-regulation does not depend on a limited resource, and that all findings could and should be understood as reflecting cognitive and motivational dynamics.

The gist of the motivation argument is as follows. In the standard two-task paradigm used for demonstrating depletion effects, the first task is typically strenuous and/or unpleasant. After doing the task, the person loses motivation to perform the second task, which causes the decline in performance that has been widely replicated. The motivational shift moves people "away from suppressing and inhibiting desires and toward approaching and gratifying them" (Inzlicht & Schmeichel, 2012, p. 451). The authors elaborated this in two motivational changes: Depletion reduces people's motivation to control themselves and intensifies their motivation to "go with [their] gut" (p. 455), that is, to act on impulse. Inzlicht and Schmeichel invoked the implicit contract notion: After exerting oneself on the first task, the participant becomes motivated to finish up and therefore underperforms on the second task.

The attention argument builds on the motivation one. Inzlicht and Schmeichel (2012) proposed that depleted persons fail to notice when they should exert control. Instead, they attend all the more to rewards.

A subsequent elaboration of the same theory by Inzlicht, Schmeichel, and Macrae (2014) asserted that the motivational shift is from "have-to" to "want-to," that is, away from what is externally required and toward what one might enjoy. We do not see how it can be adaptive to shirk necessary tasks, and indeed it could be dangerous to neglect what is required. A priori, it seems likely that the opposite shift would be more adaptive. That is, if people are indulging in unproductive, costly pleasures rather than doing things useful for survival and advancement, it would be helpful to have a signal that prompts them to shift from "want-to" to "have-to." But the motivation theorists make no case for the existence of any such signal (nor do we see how to make such a case). It seems implausible to argue that humans evolved a signal to make a motivational shift of small and dubious value while failing to evolve a parallel signal to make the opposing shift that would be much more adaptive.

As for the proposed process, Inzlicht et al. (2014) asserted, "ego depletion is a type of short-term mental fatigue." Although this might sound like energy depletion, they proposed that fatigue is not about energy but instead is "an emotion that interrupts current behavior so that alternative options can be entertained" (citing Hockey, 2013). It is "the experienced output of motivational systems that signal the need (or not) to re-prioritize one's activities" (all quotations, p. 129, Box 2). Their theory thus rests on the assumption that it is adaptive to disengage from have-to activities in favor of want-to ones. Their theory is thus an updated version of the perennial suggestion that too much self-control is bad. (Over the years, we have informally heard many researchers and theorists propose negative effects of self-control or speculate that they must exist, but published evidence for the downside of self-control remains scarce; see Baumeister & Alquist, 2009; Koval, vanDellen, Fitzsimons, & Ranby, 2015.)

This alternate theory suggests that depletion is not a state of diminished resources, but rather an adaptive motivational impetus that interrupts self-regulation so as to foster more enjoyable activities. Yet, it is unclear what would be the adaptive benefit of engaging in violent aggression against one's romantic partner (Finkel et al., 2009), for example. The glucose dynamics (including the links to premenstrual syndrome) and findings showing an improvement in strength from regular self-regulatory exercise both pose formidable challenges for a purely motivational account. A shift from "have-to" to "want-to" is hardly beneficial if the result is the intrusion of anxious worries into one's mind while taking an exam (Englert & Bertrams, 2012). How this idea would account for deterioration in visual acuity (Gröpel, Baumeister, & Beckmann, 2014) is also quite unclear. Likewise are the dubious benefits of re-prioritization when it results in deterioration in vigilance performance over time (as reviewed by Muraven & Baumeister, 2000). Sentinels and radar operators during war became less prone to notice signs of danger with time, where failure to spot an enemy could spell death for self and companions. Thus, the theory has not tried to explain the range and diversity of depletion phenomena, focusing instead selectively on the few most congenial ones (eg, reduced persistence).

3.3.1 Compatibility

The motivation and attention notions are fully compatible with the limited resource model, and indeed they make less sense without it. Because exerting control consumes a limited resource, the desire (even the mere willingness) to continue self-regulating diminishes sharply after initial exertion.

Inzlicht and colleagues invoked Hockey's (2013) theory that fatigue in general has nothing to do with low energy but is instead a signal to interrupt one's activities, reflecting opportunity and regulatory costs of perseverance. But what are those regulatory costs if not expenditure of energy? By analogy, people who physically exert themselves experience a motivational shift toward wanting to rest and not wanting to expend further effort. The motivational shift is, however, linked to the expenditure and depletion of energy. To deny that strenuous physical exertion consumes precious energy seems implausible. Why else would regulatory costs be higher if one has already self-regulated on a completely different activity?

The opportunity cost argument has difficulty explaining the multi-task paradigm findings. If fatigue were merely a signal that it is generally a good idea to switch tasks (as opposed to being a signal that one's energy has been somewhat depleted), why would it transfer so that fatigue from the first task is still felt during the unrelated second task (and indeed impairs performance on it)? Suppose that Mark must decide whether to study for tomorrow's test or go drinking with his buddies. Inzlicht and Schmeichel (2012) are correct in noting that continuing to study would bring Mark an opportunity cost: he would miss out on the potential joys of beer and inebriated conversation. But how is that opportunity cost any different by virtue of having recently stifled his anger during an argument, or skipped a tempting dessert? The carry-over of regulatory fatigue from the anger-stifling into the studying decision seemingly contradicts the signal theory. The contradiction can be resolved by regarding fatigue as a signal that energy has actually been somewhat depleted, because the energy level does carry over from one task to the next.

Furthermore, most studies of depletion fail to find any significant difference in self-reports of fatigue, and only with the increased statistical power of meta-analysis is the tiny effect significant (Hagger et al., 2010). Thus, most findings have shown that ego depletion produces significant behavioral effects without concomitant increases in subjective fatigue. Treating fatigue as a signal seems implausible if the signal is not usually received.

Likewise, Inzlicht et al. (2014) propose that the term "ego depletion" be replaced with "refractory period" so as to avoid the connotation of depleted resources. We respectfully submit that the best-known refractory period, of sexual incapacity following orgasm, characterizes the male but not the female precisely because the male but not the female orgasm depletes a limited resource (eg, Gray, 2013). Neural refractory periods likewise indicate

resource depletion. Hence again the effort to get away from resource depletion leads back to postulating resource depletion.

Meanwhile, we think the limited resource theory works better if one adds in these assumptions of motivational and possibly attentional changes. The behavioral changes caused by ego depletion could be either a direct effect of low energy or an indirect effect mediated by motivational and attentional changes. By analogy, the effects of physical tiredness can be either direct or mediated by motivational and attentional shifts. In short, not only are energy depletion and motivational change compatible, but both gain plausibility when integrated with each other. Consistent with that view are findings by Muraven et al. (2006) showing that some depletion patterns represent the desire to conserve energy, which invokes motivational assumptions: Depleted energy motivates one to conserve what remains.

3.3.2 Evidence

Inzlicht and Schmeichel (2012) proposed that depletion findings occur because the person loses motivation for the second task. Inzlicht and Schmeichel (2012) surveyed the literature and were able to find only one study that measured motivation (desire to do well) on the second task (Muraven, Rosman, & Gagné, 2007). Contrary to Inzlicht and Schmeichel's theory, it yielded a null result.

Since then, additional articles have published motivation measures, thus providing further evidence. Clarkson, Hirt, Jia, and Alexander (2010) manipulated both actual and perceived depletion and then measured motivation to perform well on the second task. Across three studies, they consistently found no change in motivation. Boucher and Kofos (2012) manipulated depletion via thought suppression and found subsequent decrements in behavioral persistence at anagrams but no change in motivation to do well on the task. Self-reported effort, another sign of motivation, also did not change as a result of depletion. A lone exception was an additional condition in which depleted participants were primed with money. Those participants did report lower effort on the second task—but nonetheless showed good performance. Thus, changes in effort showed the opposite pattern to changes in performance, contrary to the motivation account. Marcora et al. (2009) showed that a demanding cognitive task produced subsequent impairments in a physical endurance (cycling) task, but no change on several measures of motivation. Two experiments of trained soccer players also showed no evidence of self-reported motivation changes after a depleting task, despite reductions

in speed, distance, and accuracy in soccer-related tasks (Smith et al., 2016). Xiao, Dang, Mao, and Liljedahl (2014) also found no indication of changes in motivation for a final task as a function of having done one or two prior depleting tasks.

Outside the laboratory, findings again speak against motivation. An experience sampling study found evidence that ego depletion reduced the effectiveness of resisting desires—but there was no sign that depletion reduced attempts to resist desires, an indicator of whether people were being motivated to control themselves (Hofmann et al., 2012). In short, there are multiple failures to find any change in motivation as a result of ego depletion, and no significant supportive findings.

The closest supportive evidence is a recent article by vanDellen, Shea, Davisson, Koval, and Fitzsimons (2014). Depleted participants expressed less urgency than others about pursuing long-term goals. This finding does not explain behavior or performance effects, however, because the devalued long-term goals were not relevant to the current situation, and so no relevant behavior was possible (and certainly was not measured). These findings seem highly congenial to the energy depletion model: When one's energy is low, one does not feel like tackling big projects.

A direct test pitted energy conservation against reward-seeking (Giacomantoio, Jordan, Fennis, & Panno, 2014). As in previous work, depleted participants took bigger risks than other participants in the quest for obtaining large rewards—but only when risk-taking was easy. When it required energy (ie, using physical exertion to inflate a balloon), depleted participants showed significantly reduced appetite for reward-seeking, as compared to nondepleted controls. These findings emphasize that the primary effect of ego depletion is to prioritize conserving energy rather than seek rewards.

Additional evidence for the motivational account comes from Schmeichel, Harmon-Jones, and Harmon-Jones (2010). They showed that approach motivation is heightened during the depleted state, consistent with their characterization of depletion as an enhanced reward-seeking orientation. Further work by Vohs, Baumeister, Ramanathan, et al. (2016) and Vohs, Baumeister, Vonasch, Pocheptsova, and Dhar (2016), however, has shown that the depleted state intensifies a broad range of desires and feelings, both positive and negative. Brain data by Wagner and Heatherton (2013) likewise showed increased amygdala reactivity among depleted participants when viewing upsetting images, suggesting an increased emotional response. Gailliot et al. (2006) found that thoughts of death emerged into

consciousness more when people were depleted than not depleted. These papers indicate that the effect of depletion is more than simply to make people motivated to attain pleasant or appealing rewards.

Hence the emphasis on approach motivation seems unduly narrow. To be sure, the conclusion that both approach and avoidance motivations increase during ego depletion does not contradict all motivational accounts, even though it does not fit the specific one advanced by Inzlicht and Schmeichel (2012). It does, however, suggest that any motivational theory would have to be reformulated as producing a general increase in motivational intensity rather than contributing to specific motivations. The general increase in motivational intensity, alongside an increase in emotional and other evaluative reactions, seems most compatible with an integrative model, by which a resource has been depleted, causing changes in allocation and motivational investment aimed at preserving what remains of the resource. Indeed, if reduced executive activity generally is linked to increases in evaluative intensity, then both resource depletion and increased motivation would ensue. This is what we think happens.

Another line of argument in the motivational account is that doing the first task provides an implied psychological "license" to slack off later. Inzlicht and Schmeichel (2012) emphasized the idea that the first task is often aversive or at least effortful, and so people may feel entitled to take it easy on the second task. Inzlicht and Schmeichel note, correctly, that this motivational shift could account for the many findings in which depleted participants reduce the duration of persistence on the second task. However, that interpretation would be contradicted if participants ever spent longer times on the second task, as doing so would keep them for a longer time at the experiment. Their theory thus invokes the implicit contract notion and is contradicted by the evidence against that theory, as covered in the preceding section.

There is less work available on attention. Lubusko (2006) tested the hypothesis that participants with attention deficit hyperactive disorder (ADHD) would be more affected than normal controls by a depletion manipulation. That was not supported. Critcher and Ferguson (2014) found that monitoring oneself is depleting, which seemingly extends the resource-depletion model to cover attentional effort—instead of indicating that attentional processes could replace the resource-depletion idea.

Ultimately, the motivational reformulation by Inzlicht et al. (2014) is centered on the assertion that there are clear adaptive benefits of withdrawing from self-control activities after a while. Both too much and too little

self-control would be maladaptive, and negative outcomes should be documented for both very high and very low self-control. Medium levels of trait self-control would be best. Abundant evidence flatly contradicts these predictions. For example, Tangney et al. (2004) performed extensive analyses on the effects of trait self-control looking for any signs of a downturn in outcomes at high levels of self-control, but found none: High self-control, not medium, produced the best outcomes (see also Moffitt et al., 2011; for meta-analysis, de Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012).

Inzlicht et al. (2014) might claim that the benefits of interrupting self-control would take the form of happiness and pleasure rather than objective, pragmatic benefits, and indeed their account of shifting from have-to to want-to suggests precisely that. Again, the data refute that assertion: self-control appears to have a positive linear relationship to happiness (Hofmann, Luhmann, Fisher, Vohs, & Baumeister, 2013), rather than a curvilinear or negative one as their theory implies.

The postulate that depletion is an adaptive way of facilitating positive outcomes has not been supported, as the overwhelming bulk of evidence of effects of depletion are negative. Even the scattered evidence of positive effects we reviewed earlier does not conform to the pattern of facilitating "want-to" goals. Instead, depletion simply makes people susceptible to external cues, and when these are strongly set up to facilitate positive behavior, depletion increases positive behavior.

3.3.3 Conclusion

Changes in motivation and attention may occur following exertion of self-control. These seem most plausible as stemming from a reduction in resources, so these changes should best be understood as potentially extending rather than replacing the limited resources model. The crucial prediction that exerting self-control reduces motivation to perform well on the second task has not been supported, and indeed null results are accumulating. There is some evidence that all motivations are felt more strongly during the depleted state than otherwise. This is, however, a general intensification of feeling rather than the specific motivational changes posited by Inzlicht and colleagues (Inzlicht & Schmeichel, 2012; Inzlicht et al., 2014). In short, it is intuitively and theoretically appealing to suggest that motivational changes mediate the effects of energy depletion, but evidence thus far is weak.

The more radical version of the motivation theory, which seeks to discard the notion of limited energy and conceptualize phenomena solely in terms of motivational and attentional changes, has multiple and serious shortcomings. Evidence that depleted people are responding to a signal to reduce motivation is severely lacking. Evidence for the assertion that depletion enables people "to strike an optimal balance between engaging cognitive labor to pursue 'have-to' goals versus preferring cognitive leisure in the pursuit of 'want-to' goals'" (Inzlicht et al., 2014, p. 1364), or indeed any evidence that depletion leads to adaptive outcomes as the theory insists, also is lacking. Crucially, the motivational account seems unable to cope with many of the phenomena associated with depletion, including enhancement of negative feelings, alterations in critical fusion frequency, and the restorative effect of glucose.

In our view, the prospect of discarding the limited resources idea and explaining all depletion phenomena based on motivation and attention seems untenable. A more promising line of theory development would be to elaborate how depletion of a precious and limited resource causes changes in motivation and attention. Direct evidence of such changes in motivation and attention would help to flesh out this aspect of the theory and render it plausible.

3.4 Other Motivational Accounts

Self-control activities often feel effortful, the experience of which Kurzban, Duckworth, Kable, and Myers (2013) posited is the conscious output of the desire not to continue with a persistence task. Their theory states that people perform cost-benefit analyses when performing a self-control task because they recognize that there are opportunity costs to continuing. That is, they propose that depletion effects occur because people realize that there are better things to do with their time than persisting any longer on the assigned experimental task.

Their model is another version of the implicit contract theory and thus suffers from its problems. Opportunity costs are relevant only to self-control outcomes where duration of persistence is the measure of self-control, so it is ill suited to explaining the rest of the effects. The opportunity cost-benefit analysis does not apply to the emergence of prejudices and biases, accuracy on mental tasks, vice over virtue choices, increased interference by anxiety, or a number of other self-control outcomes that have little to do with the

amount of time one spends (eg, Richeson & Trawalter, 2005; Vohs et al., 2008; Wang et al., 2010).

Likewise, the central idea that depletion is essentially a realization that one should cease the current task and do something else has difficulty accounting for the carry-over of depletion from one task to another, which is the main pattern in most depletion findings. Why doing one task should change the value of persevering on a very different second task is quite unclear—unless, of course, both tasks consume the same kind of energy, and the first task has depleted it so that one needs to conserve.

Even within their article, Kurzban et al. (2013) provided little evidence to support their theory. They cited evidence that people often report that exerting self-control requires conscious effort. There was no evidence that people are performing cost–benefit analyses during self-control, nor that the sense of effort is a sign that one has more worthwhile ways to spend time than the present task. Indeed, it long has been known that people are not inclined to exert extra mental effort in order to do many mental tasks (Fiske & Taylor, 1984), and that is especially true after people have used self-control (Schmeichel et al., 2003), so the occurrence of these cost-benefit calculations is questionable on theoretical grounds. The only study we know that directly invoked such calculations found results contrary to what Kurzban et al. proposed: These calculations of whether to engage in an activity were reduced rather than increased as leaders became depleted (DeWall et al., 2011). What is more, Kurzban et al. (2013) seemed to postulate a limited resource anyhow, one that is "inite, dynamic, and divisible" (p. 667). This sounds much like the limited resource in the strength model.

Glucose findings are difficult to reconcile with the motivational perspectives of both Kurzban et al. (2013) and Inzlicht and Schmeichel (2012). An early study by Gailliot et al. (Gailliot, Baumeister, et al., 2007 though at the journal editor's suggestion this experiment was deleted from the published article) tested the hypothesis that indulging in pleasure would increase willpower, possibly by restoring the participant's willingness to work hard for the experiment (see implicit contract notion). However, both the good tasting and bad tasting food restored self-regulation, so it was not the pleasure that was responsible for it, nor presumably the participant's grateful motivational willingness to exert on the upcoming task. Other findings have often shown that good tasting drinks or snacks without glucose, such as diet sodas, produce no improvement in self-regulation (eg, Masicampo & Baumeister, 2008; McMahon & Scheel, 2010; Wang & Dvorak, 2010). Such findings indicate that the physical substance and physiological process are crucial, rather than merely stimulating motivation via grateful appreciation of a treat.

3.5 "All in Your Head" Beliefs

Another major challenge is the idea that depletion is "all in your head," as asserted in the title of a provocative article by Job et al. (2010). They found that depletion effects could be eliminated insofar as people believed that their willpower was unlimited. A follow-up study even found that getting a glucose dose when depleted had no effect on people who held the belief in unlimited willpower (Job, Walton, Bernecker, & Dweck, 2013).

To be sure, the conclusion must be suspected on a priori grounds. Failure at self-control is costly to both individuals and society. If it were possible to eliminate many such failures simply by cultivating belief in unlimited willpower, then presumably most successful cultures and individuals would have come round to that belief long ago. The perseverance of a problematic belief instead of a much more appealing and more adaptive alternative is hard to explain—unless, of course, the belief is correct.

The notion that mindsets could offset depletion effects was preceded by a simpler finding making the same point. Martijn et al. (2002) had people engage in affect regulation and told some of them that they could perform well on a handgrip stamina task after regulating emotions. Without that expectancy manipulation, they replicated the usual depletion effect. The standard depletion effect was eliminated and even significantly reversed when people were told that they would perform better at physical exertion following an emotion regulation task. Thus, again, subjective expectancies of being impervious to depletion were able to overcome the effects of depletion. A second study found that most people tend to hold a mental model that self-control requires energy, as compared to a model that implies that self-control is a function of motivation.

3.5.1 Compatibility

The implicit beliefs view could potentially replace the theory of depletion as the expenditure of a limited resource. According to Job et al. (2010), no resource is actually depleted, and instead the phenomena of depletion are "all in the head" (ie, illusory). The belief in limited willpower could be understood as a tragic mistake: if only they had known to regard their resources as unlimited, they could have performed successfully and behaved in a virtuous or disciplined manner.

Implicit theories could be quite compatible with the limited resource model after all, especially in light of the shift from resource exhaustion to allocation. As already noted, there is no need to conserve a resource that is unlimited. Encouraging people to believe that their willpower is unlimited

seems an obvious way to get them to continue to allocate resources to the task at hand. Insofar as depletion effects are based on conserving a limited and partly depleted resource, then those effects could be overcome by removing the perceived need to conserve.

3.5.2 Evidence

The Job et al. (2010) findings were replicated by Vohs et al. (2013), who found the effect to be specific to mild depletion. In cases of severe depletion, the benefits of believing in unlimited willpower were eliminated and even significantly reversed. That is, after participants initially performed a series of four depleting tasks, those who believed in unlimited willpower performed no better and indeed, for one outcome, performed significantly *worse* than those with the standard belief in limited willpower. The latter finding can perhaps explain why world cultures have not generally embraced the belief in unlimited willpower: In cases of severe depletion, the belief may be counterproductive. These findings also fit the integrative position. Believing in unlimited willpower removes the perceived need to conserve the resource after some has been expended. In this view, however, it is the belief in unlimited willpower that is apparently mistaken. The person continues to allocate resources to the current tasks based on believing them to be unlimited, but in reality the resource is limited. Hence, as the depletion increases from mild to severe, the effects can no longer be concealed. By analogy, one could imagine a consumer mistakenly believing his or her finances were unlimited and therefore overspending. The consumer thus fails to rein in spending as most people would after initial expenditures—but then eventually suffers an acute shortage of funds.

The glucose findings by Job et al. (2013) were widely publicized but suffered from several drawbacks. One is the obvious demand characteristic: After saying willpower is unlimited, people might feel an obligation to persevere, regardless of glucose. Job et al. did not measure glucose and so one can only infer what inner processes contributed to their finding. In contrast, Ainsworth et al. (2016) did measure glucose in combination with the implicit theory manipulations used by Job et al. They found that depleted people with belief in unlimited willpower actually showed a significant increase in blood glucose levels just before the second task. (Those with belief in limited willpower had no change.) Thus, inducing belief in unlimited willpower caused people to allocate more glucose to the current task, which is precisely what one would expect if one were to perceive a resource as unlimited. Moreover, in a severe depletion condition, glucose levels were

low regardless of beliefs in limited vs unlimited willpower. These findings fit the central governor and selective allocation theories of limited resources. With mild depletion, a belief in unlimited willpower encourages the person to continue allocating resources, while those who believe willpower is limited begin to conserve. In the long run, however, the effects of resource depletion affect everyone, regardless of personal beliefs and implicit theories.

Although we have replicated the Job et al. (2010) effects, it must be acknowledged that other findings conflict with them. The next section will cover four studies by Clarkson et al. (2010), all of which found depletion combined with belief in having abundant resources produced poor self-regulatory performance.

3.5.3 Conclusion

The implicit theories work does not challenge depletion theory. The effects of depletion may be delayed but not canceled by cultivating belief in unlimited willpower. The implicit theories phenomena should be grouped with the other findings indicating that people can still perform well despite mild depletion, though at some cost to subsequent self-regulatory capacity.

3.6 Perceived Depletion

A variation on the Job et al. (2010) view that depletion is "all in your head" is that the self-regulatory failures during the depleted state are based on the *perception* that one's resources are depleted, rather than the reality. Relevant studies by Clarkson et al. (2010) manipulated both actual depleting effort and perceived depletion in a factorial design. Participants performed a depleting or nondepleting task. Next, half of each group was told that the task would "mentally exhaust" their ability to attend to information and think carefully. The others were told that the task would "energize and replenish" their ability to attend and think. Then self-regulatory performance was measured.

Many of their results fit the simple assumption that either perceived depletion or actual depletion can impair performance. In neutral conditions, with no manipulation of perceived depletion, the standard depletion effect was replicated: People who exerted more resources on the first task performed worse on the second task. A more novel finding was that performance on the second task also suffered among participants who did a nondepleting first task but were told the task would exhaust and deplete them. In another novel finding, participants who did exert initial effort

(actual depletion) but were told the task would refresh and replenish them also performed worse on the second task.

The difficulty lies in yet another condition, in which people first performed a depleting task and then were told that the task would make them feel exhausted and depleted. They performed well. Clarkson et al. (2010) replicated this in four experiments (and yet again in Clarkson, Hirt, Chapman, & Jia, 2011). That is, the combination of actual and perceived depletion paradoxically produced the opposite effect than what would have been predicted, enabling people to perform like people who enjoyed the full powers of their resources.

Why? Information about the ostensibly depleting nature of the task influenced people. Clarkson et al. (2010) proposed that nondepleted persons used that information to *interpret* their state, whereas depleted ones used it to *explain* their state (p. 43, italics in original). We remain confused. Their explanation does not entirely fit their findings. They claimed to have shown that depleted individuals can still self-regulate effectively if led to believe they have ample resources available (p. 43). We agree in principle, but in all four of their studies, performance was poor in the condition in which people were actually depleted and then led to believe they had ample resources. (This pattern thus also contradicts what Job et al. (2010) found, which is that perception of having ample resources counteracts depletion.) The good self-regulatory performance came precisely when one would have expected the most severe depletion, namely, when people both were actually depleted and were led to perceive themselves as depleted. One possible explanation is that the double signal of depletion prompted the system to release more glucose from stores, producing an effect like the so-called "second wind" familiar to distance runners. This hypothesis (which also suggests higher blood glucose levels) cannot be asserted with any confidence until some glucose data become available, but it represents one way of integrating and reconciling these findings.

3.7 Mere Taste of Glucose

Multiple findings from different labs have shown improvement in self-regulation or decision making as a result of consuming glucose (Danziger et al., 2011; Gailliot, Baumeister, et al., 2007; Gailliot, Plant, et al., 2007; Masicampo & Baumeister, 2008; McMahon & Scheel, 2010; Wang & Dvorak, 2010). These seemingly confirmed the view that self-regulation depends on consuming fuel in the form of glucose. In these studies,

consuming glucose did not benefit people in nondepletion conditions, that is, without prior exertion of self-regulation or decision making. Consuming equally tasty drinks or snacks without glucose provided no benefit, so it was not a matter of pleasure stimulating gratitude or other motivational changes.

The glucose findings attracted considerable interest, not least because they seemed capable of moving willpower theory from metaphor to physiology. An intriguing challenge emerged from findings that depletion effects were eliminated among people who did not actually consume an entire glucose drink but merely swished it around in the mouth for 5 s and then spat it out (Molden et al., 2012). That work also found that rinsing the mouth produced no significant rise in blood glucose levels and that its effects on behavior began immediately, both of which are incompatible with the view that the newly ingested glucose is used as fuel for new acts of self-regulation. Similar findings have been reported by Hagger and Chatzisarantis (2013). Rinsing the mouth with glucose solution and then spitting it out counteracted the behavioral effects of depletion. Rinsing with a diet sweetener solution had no effect, and the glucose rinse had no effect apart from depletion. Those authors cite evidence that control-oriented brain regions such as the anterior cingulate cortex (ACC) show increased activity in response to the taste of glucose. Such an increase might plausibly offset a reduction in activity caused by ego depletion.

To be sure, glucose receptors exist in the mouth, enabling some glucose to get into the bloodstream even if the person does not swallow (Kurosaki, Yano, & Kimura, 1998). But still, this would only be a small amount and presumably not enough to replenish depleted stores of willpower. It would, however, solve the mystery of why some beverages (eg, with diet sweetener) fail to produce any effect.

Some writers were tempted by the mere taste findings to conclude that glucose is irrelevant to self-regulation. However, given the evidence that the brain's glucose use does increase during strenuous thought (eg, Buchsbaum et al., 1990; Haier et al., 1992), it seems likely that self-regulation may increase glucose consumption and that adjustments are made based on glucose availability and usage.

The central governor and selective allocation theory provides a useful way of understanding these effects. The mere taste or initial consumption of a small amount of glucose functions as a physiological signal that more fuel is coming. This could operate much like the belief in unlimited willpower: The person feels there is no need to conserve energy, even if some has been expended, because more is on the way. This line of analysis also

explains the immediacy findings: if glucose consumption can improve performance immediately, it would not be because the food has been digested, but rather because the first bits of glucose to enter the system serve as a signal that more is coming—so there is less need to conserve.

3.8 Expressing the Self

Moller, Deci, and Ryan (2006) proposed that making decisions is depleting only insofar as one is subject to external control, whereas truly autonomous choosing is not. They showed that when people made one or two pleasant, internally directed choices rather than externally mandated ones, they did not experience ego depletion. At that time, the only published evidence that choosing depletes the self was a dissonance study from Baumeister et al. (1998). That study was highly congenial to the Moller et al. analysis, because, as in much dissonance research, the participant was subtly pressured into agreeing and then reminded that the decision was "up to you." Thus, agreeing to write a counterattitudinal essay would hardly be considered a spontaneous act of an autonomous self.

Subsequent work by Vohs et al. (2008) replicated Moller et al.'s finding that the depleting effects of choosing can be eliminated when choosing is an expression of one's preferences—provided that not many choices are needed. When participants engaged in a decision task (a bridal registry) for 4 min, only those who disliked the task were depleted. Those who enjoyed it showed no depleting effects. But among participants assigned to make choices for 12 min, depletion was observed regardless of enjoyment.

Some evidence suggests that choosing is most depleting when tied to pragmatic consequences for oneself. Choi and Fishbach (2011) found that making many choices depleted the self's resources, consistent with Vohs et al. (2008). Depletion was found only when people made choices in order to gain something from the choice, and not when choosing was framed as "choosing for its own sake," that is, when instructed to use decisions as a way to indicate their personal tastes and preferences as opposed to actually get something from them. In that latter condition, people reported feeling more energized than compared to participants who made few or no choices. The act of making a decision is not taxing, it seems, if the choice is not tied to an instrumental goal.

How depleting it is to make decisions rests on who will bear the consequences of them. Polman and Vohs (in press) found that people who prioritize

the self showed depletion effects after making choices for themselves, whereas, in contrast, people who prioritize others showed depletion effects after making choices for others. What seems to matter with decision fatigue is whether the choice outcomes will be levied on someone one cares about.

Making freely chosen decisions lessens depletion effects, at least for a while. Graham et al. (2014) showed that instructions bolstering autonomy could overcome depletion effects. People who were told that their participation was important and that all decisions about effort were up to them performed better after depletion than those who were told that they were required to do their best (see also Muraven et al., 2008). Once again, however, the effect disappeared and was even reversed in a severe depletion condition involving multiple tasks. As the authors note, these results strongly point to an energy depletion model. Bolstering autonomy can inspire people to put forth greater effort in the short run, but it does not increase their energy supply, so the greater short-term effort results in greater depletion and hence poorer performance later.

The findings in this section fit the view that expressing the self can counteract mild depletion. Making choices that are self-chosen and express the self's preferences reduced the effects of depletion. Severe depletion, such as caused by making many decisions, produces impairments and other signs of depletion, regardless of feelings of autonomy. Thus, these findings fit the strength model and resemble other evidence that mild depletion can be overcome by encouraging more allocation.

4. CONCLUSIONS

Our research program, substantially enriched by contributions from many other laboratories, has continued to find that self-regulation operates as if powered by a precious, limited resource. In particular, ego depletion has been found in many different contexts: After initial exertion of self-control or other top-down control, subsequent exertions in even seemingly unrelated contexts suffer.

Understanding self-regulation is important, not least because of the many adaptive long-term benefits that stem from good self-control. The implications are even broader, however. Does the human self consist partly of a well of energy that is used for volition? The idea can be traced back at least to Freud—but few subsequent theorists have embraced it. The strength model thus revives an energy perspective that had been absent from self theory for decades.

Thus, the energy theory of self is at once highly novel and ancient. It should not be surprising that the theory has continued to evolve as well as to be challenged by other theorists seeking to explain the phenomena using the more familiar explanatory tools of motivation, attention, beliefs, expectancies, and the like.

In our view, the strength model emerges from these challenges as still viable and indeed the best way to account for all the findings. To be sure, we found substantial merit in several of the viewpoints others have espoused. But these worked best as refinements and additions to the theory rather than replacements for it. Indeed, some of them lacked conceptual coherence without the foundational assumption of a limited resource.

We have embraced much of Beedie and Lane's (2012) allocation account, for example—but selective allocation nevertheless suggests that a limited resource needs to be allocated. The motivation and implicit beliefs accounts likewise work best in combination with the assumption that there is a limited resource. In general, we found that the more theories radically departed from the limited resource assumption, the less plausible and less well supported they were. For example, the view that resource depletion can be entirely replaced by positing changes in motivation to exert oneself on the second task (after having done the first) has now failed to receive support in a series of experimental tests in different laboratories. Likewise, the implicit contract notion and the dismissive "all in your head" view have been contradicted by multiple findings. That work does, however, make valuable, useful contributions when integrated into the strength model.

At present, the most serious challenge to the resource-depletion view is the lack of close correspondence between ego depletion patterns and glucose availability. It is not tenable to argue that ego depletion arises because the brain has run out of fuel or even that it is arises when the body's reserves of glucose are close to empty. Nonetheless, there is ample evidence that glucose is relevant to ego depletion, including the findings that low glucose reliably predicts poor self-regulatory performance, and that a dose of glucose counteracts depletion. Quite plausibly, depletion is based on how much glucose has recently been consumed rather than on the amount remaining available.

The central governor theory, advanced by Evans et al. (2015), helps resolve theoretical problems. The body developed systems to protect its glucose stores, probably in connection with being ready to furnish considerable energy to the immune system whenever needed. The central governor

restricts glucose use so as to conserve, and it does so without knowing precisely how much is available, operating instead on the basis of an implicit budget that seeks to keep daily glucose use from outstripping consumption—such as by freely expending available new glucose but only reluctantly dipping into stores.

The central governor theory explains why so many different procedures can temporarily counteract depletion: The governor uses all available cues, because it does not know how much remains, and moreover it must be willing to allocate extra glucose in a crisis. For example, if one is being chased by a predator, it would be adaptive to allocate plenty of glucose rather than conserving for a future that may never happen. It explains the differences between mild and severe depletion, which is important given that this difference posed huge problems for several of the competing theories. The central governor does not have the most important information, namely, how much glucose exists in storage around the body, so it uses various cues, such as the information suggesting that willpower is unlimited. Such a belief can override the cues from a modest accumulation of adenosine, indicating that some glucose has been consumed. But as the ashes pile up, the central governor pays more attention to that signal than to other inputs (such as manipulated beliefs). The central governor also accounts for the findings that a mere taste of glucose can counteract depletion: A taste of glucose is normally a signal that more energy is coming in, so it can expend more freely.

Hence, we think that self-regulation does in fact depend on consuming a limited resource, and that people act as if their actions consume energy—even though their responses may be only weakly and indirectly linked to actual glucose consumption and reserves. The alternative views have offered valuable insights that challenge and enrich the strength model, but they have failed to provide a viable alternative account for the full range of findings. Advancing the field's understanding of self-regulation would be better served by refining the strength model based on new findings and insights, rather than by ambitious assertions that it can be discarded and replaced.

4.1 Future Directions

The present review suggests priorities for further empirical work on self-regulation. The idea that energy is used for self-regulation and other executive functions appears solid for now. Rather than debating whether energy models can be discarded in favor of attributing all the phenomena to mistaken beliefs, various other cognitive processes, or motivational shifts, it

seems more promising to inquire how these factors work together with energy.

The strength model was originally formulated to account for self-regulation and was then extended to include effortful decision making. Future work should delineate what other processes deplete the resource. We cited some work indicating that depletion shifts people from initiative (active, self-starting behavior) toward passivity and mentioned some small evidence that planning (specifically, implementation intentions) is relevant. Planning and initiative deserve more study. Identifying any other activity that draws on the resource would strengthen and expand the theory. Links between self-regulation and other physiological processes (eg, PMS, chronic pain, liver functioning, immune functions) seems a promising way to gain powerful insights.

Another key question is what else causes ego depletion, beyond the deliberate exercise of cognitive control. We cited some findings that experiencing situational uncertainty causes depletion. The possibility that strength is depleted by stress and/or coping has begun to attract research attention, but thus far results have been mixed and inconclusive.

We regard studies of severe depletion as a high priority. The meta-analysis by Hagger et al. (2010) included over a hundred studies, and at least that many more have been published since then, but nearly all of them have focused on mild depletion, such as occurs after 5–10 min of relatively modest exertion. The studies that have included conditions with more extensive depletion have often found notable differences as compared with mild depletion (eg, Ainsworth et al., 2016; Vohs et al., 2008, 2013)—in particular, some factors that moderate the effects of mild depletion have failed to do so with more extensive depletion. Studying low-SES people might also help in investigating severe depletion (Miller et al., 2015).

Studies of severe depletion might also address questions of chronic depletion. We have conceptualized depletion as a temporary state, from which the person recovers in fairly straightforward manner with food and rest. It is conceivable that using self-control in inhospitable environments, burnout, and post-traumatic stress disorder have some elements of chronic depletion, thus impairing self-regulation to an extent that it does not bounce back after a healthy dinner and good night's sleep. At present, the notion of chronic depletion remains purely speculative, but it holds some promise of being able to shed light on the sufferings of many unfortunate individuals.

Meanwhile, the improvement in performance caused by frequent exercise of self-control requires elucidation. Both theory and practice would

benefit from improved understanding of what inner processes, systems, and mechanisms change as a result of regular exercise at self-regulation. Possibly the central governor learns that it can continue allocating glucose for a longer period than it had previously assumed, or perhaps physiological processes become more efficient with frequent use.

Last, there is much yet to be learned about the physiological processes, including the role of glucose. Brain processes need to be integrated with a better understanding of how glucose is stored and used in the body outside the brain (eg, liver). It seems indisputable that glucose plays a central role in self-regulation, but many questions remain about how that happens. Moreover, glucose is probably not the whole story, and the roles of other biochemical processes (eg, adenosine) deserve elucidation.

4.2 Final Remarks

Folk wisdom has long invoked the notion of willpower as a key ingredient for successful self-control and self-discipline, suggesting that energy is consumed in such acts of volition. Psychological theory dispensed with energy models for decades. Skepticism and even hostility toward explaining self-regulation in energy terms are to be expected. Yet the alternative versions generally have large conceptual gaps that cannot be filled without subtly reintroducing the idea of depleted energy resources, or at least resources of some sort. The traditional folk notion of willpower as a limited supply of energy that fuels effort and virtue has proven surprisingly durable, and if updated with new findings, it still forms the basis for a promising scientific account of human volition.

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