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Managing temptation in obesity treatment: a neurobehavioral model of intervention strategies

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Abstract

Weight loss outcomes in lifestyle interventions for obesity are primarily a function of sustained adherence to a reduced-energy diet, and most lapses in diet adherence are precipitated by temptation from palatable food. The high nonresponse and relapse rates of lifestyle interventions suggest that current temptation management approaches may be insufficient for most participants. In this conceptual review, we discuss three neurobehavioral processes (attentional bias, temporal discounting, and the cold-hot empathy gap) that emerge during temptation and contribute to lapses in diet adherence. Characterizing the neurobehavioral profile of temptation highlights an important distinction between *temptation resistance strategies* aimed at overcoming temptation while it is experienced, and *temptation prevention strategies* that seek to avoid or minimize exposure to tempting stimuli. Many *temptation resistance* and *temptation prevention* strategies heavily rely on executive functions mediated by prefrontal systems that are prone to disruption by common occurrences such as stress, insufficient sleep, and even exposure to tempting stimuli. In contrast, commitment strategies are a set of devices that enable individuals to manage temptation by

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BMA conceptualized and drafted the initial manuscript. All authors participated in refining the perspectives discussed in the manuscript, and critically revised the manuscript for important intellectual content. All authors have approved of the manuscript in its final form.

constraining their future choices, without placing heavy demands on executive functions. These concepts are synthesized in a conceptual model that categorizes temptation management approaches based on their intended effects on reward processing and degree of reliance on executive functions. We conclude by discussing the implications of our model for strengthening temptation management approaches in future lifestyle interventions, tailoring these approaches based on key individual difference variables, and suggesting high-priority topics for future research.

Keywords

Diet adherence; Obesity; Lifestyle intervention; Food reward; Temporal discounting; Commitment; Executive function

Introduction

Obesity is a risk factor for multiple health conditions (Abdullah, Peeters, de Courten, & Stoelwinder, 2010; Bogers et al., 2007; Guh et al., 2009; Hubert, Feinleib, McNamara, & Castelli, 1983; Renehan, Tyson, Egger, Heller, & Zwahlen, 2008; Strazzullo et al., 2010) and affects about one-third of adults and one-sixth of children in the U.S. (Ogden, Carroll, Kit, & Flegal, 2014). Obesity contributes to 9% of all medical expenditures in the U.S. (Trogon, Finkelstein, Feagan, & Cohen, 2012), and this figure is projected to grow substantially in coming decades (Finkelstein et al., 2012). Effective and affordable approaches to prevention and treatment are urgently needed.

The current front-line therapy for obesity consists of comprehensive lifestyle intervention focused on dietary modification, physical activity, and behavior change strategies (Jensen et al., 2014). Roughly 50% of lifestyle intervention participants lose at least 5-10% of initial body weight (Dansinger, Tatzioni, Wong, Chung, & Balk, 2007; Pi-Sunyer et al., 2007), which is the minimum benchmark for conferring clinically meaningful improvements in cardiometabolic risk factors (Dow et al., 2013; Liu, Wharton, Sharma, Ardern, & Kuk, 2013; Wing et al., 2011). The remaining half of lifestyle intervention participants are nonresponders with respect to this outcome. In addition to high nonresponse rates, relapse is common (perhaps the norm). About one-third to one-half of lost weight is regained within one year of treatment discontinuation (Barte et al., 2010; Curioni & Lourenco, 2005; Franz et al., 2007). Even with ongoing, long-term intervention, only about 3.2 kg or 4-5% of lost weight is maintained (Look AHEAD Research Group, 2014; Middleton, Patidar, & Perri, 2012). Increasing response rates and reducing relapse are top priorities for behavioral obesity treatment (MacLean et al., 2015).

One path toward improved weight loss outcomes involves strengthening intervention strategies to help participants manage temptation from the highly palatable but unhealthy foods that permeate modern society. Weight loss outcomes are largely a function of sustained behavioral adherence to any reduced-energy diet (Alhassan, Kim, King, & Gardner, 2008; Dansinger, Gleason, Griffith, Selker, & Schaefer, 2005; Fitzpatrick et al., 2014; Heymsfield et al., 2007), and are not meaningfully affected by the *type* of diet one follows (Ajala, English, & Pinkney, 2013; Hu et al., 2012; Wycherley, Moran, Clifton,

Noakes, & Brinkworth, 2012). Most dietary lapses are precipitated by temptation from palatable food (Cleobury & Tapper, 2014; McKee, Ntoumanis, & Taylor, 2014; Thomas, Doshi, Crosby, & Lowe, 2011). Thus, a promising route to better weight loss outcomes would be to design interventions that not only include diet plans with high acceptability and feasibility (Makris & Foster, 2011; Pagoto & Appelhans, 2013), but also arm patients with effective temptation management strategies.

In this review, we examine the neurobehavioral underpinnings of temptation, and highlight three processes that undermine diet adherence. We then review temptation management strategies in terms of their intended effects on temptation and the demand each strategy places on executive functions. Based on these considerations, we construct a model of temptation management strategies that we hope will guide future efforts to improve weight loss outcomes, particularly in participants who do not respond or relapse with traditional lifestyle interventions.

Food reward as the basis of temptation

Eating is regulated by two distinct but interconnected neurobehavioral systems: a homeostatic system and a reward-based system. In the homeostatic system, food is a component of a physiological-behavioral homeostatic feedback loop that governs energy balance (reviewed elsewhere; Berthoud, 2012; Harrold, Dovey, Blundell, & Halford, 2012; Hussain & Bloom, 2013; Rui, 2013; Woods & D'Alessio, 2008). In contrast, the reward system influences eating in response to the sensory experience of food. Two dimensions of reward have been distinguished in the literature (Berridge, 2009; Berridge, Ho, Richard, & DiFeliceantonio, 2010; Berridge & Kringelbach, 2008; Berridge & Robinson, 2003; Fulton, 2010; Kringelbach, Stein, & van Hartevelt, 2012). *Liking* reflects the hedonic aspect of reward and applies to the sensory pleasure associated with eating palatable food. *Wanting*, in contrast, manifests as appetitive motivation, desire, craving, and temptation; it is the dimension of reward that challenges self-control. *Wanting* underlies engagement in a variety of appetitive behaviors, including sexual activity (Georgiadis & Kringelbach, 2012), gambling (Joutsa et al., 2012; van Holst, van den Brink, Veltman, & Goudriaan, 2010), and substance abuse (Koob & Volkow, 2010; Pulvirenti & Koob, 1990; Robinson & Berridge, 1993; Schacht, Anton, & Myrick, 2013). When applied to food, *wanting* provides the motivational drive that supports adaptive foraging and hunting behaviors in environments of scarcity (Alcaro & Panksepp, 2011), but contributes to overeating in modern environments characterized by an abundance of hyper-palatable foods that can be obtained with minimal effort. Though *liking* and *wanting* may not be phenomenologically distinct in most day-to-day human experiences (Havermans, 2011), it is increasingly recognized that reward, rather than energy homeostasis, is the primary driver of overeating in modern society (Lowe & Butryn, 2007). Individual differences in food reward processing (Finlayson, King, & Blundell, 2007b; Mela, 2006), reflected in a variety of behavioral (Appelhans et al., 2011b; Epstein, Carr, Lin, & Fletcher, 2011; Epstein, Leddy, Temple, & Faith, 2007; Finlayson, King, & Blundell, 2008; Finlayson, King, & Blundell, 2007a; Giesen, Havermans, Douven, Tekelenburg, & Jansen, 2010; Lansigan, Emond, & Gilbert-Diamond, 2015; Saelens & Epstein, 1996) and biological (Burger & Berner, 2014; Burger & Stice, 2014; Demos, Heatherton, & Kelley, 2012; Guo, Simmons, Herscovitch, Martin, & Hall, 2014; Jonsson et

al., 1999; Stice, Spoor, Bohon, & Small, 2008; Stice, Yokum, Burger, Epstein, & Small, 2011; Volkow et al., 2008) measures, are implicated in obesity risk. While the notion of “food addiction” remains controversial (Blundell & Finlayson, 2011; Smith & Robbins, 2013; Wise, 2013), frequent encounters with tempting foods in the modern environment, which activate the brain’s reward circuitry and trigger an appetitive motivational cascade, continuously challenge dieters’ self-control and adherence.

The neurobehavioral profile of temptation

The influences of several neurobehavioral processes emerge during the experience of temptation: reward-driven attentional biases, temporal discounting, and the cold-hot empathy gap. Collectively, these processes constitute an altered neurobehavioral profile that undermines diet adherence.

Attentional bias

Reward is a strong modulator of cognitive control (Braver, 2012), having both bottom-up and top-down influences of reward on attention allocation. Motivationally salient stimuli in the environment preferentially attract reactive attention, and conversely, one’s motivational state affects the extent to which attention is proactively directed to seeking out reward-related stimuli (Anderson, 2013; Anderson, Laurent, & Yantis, 2011, 2013; Awh, Belopolsky, & Theeuwes, 2012; Chiew & Braver, 2014; Della Libera & Chelazzi, 2006; Wang, Duan, Theeuwes, & Zhou, 2014). As a rewarding stimulus, food elicits several forms of attentional bias, including greater susceptibility to distraction by food cues, more rapid detection of food cues in the visual field, and greater difficulty disengaging attention from food cues (Pool, Brosch, Delplanque, & Sander, 2014). These biases are enhanced in a state of hunger or food craving (Castellanos et al., 2009; Kemps & Tiggemann, 2009; Loeber, Grosshans, Herpertz, Kiefer, & Herpertz, 2013; Piech, Pastorino, & Zald, 2010; Smeets, Roefs, & Jansen, 2009; Werthmann, Roefs, Nederkoorn, & Jansen, 2013), particularly for palatable, energy-dense foods (Doolan, Breslin, Hanna, Murphy, & Gallagher, 2014). Attentional biases may potentiate the appetitive pursuit of rewards by keeping individuals locked onto rewarding stimuli until they are consumed (Alcaro, Huber, & Panksepp, 2007; Berridge, 2004). Thus, for obese individuals participating in lifestyle interventions, palatable food may act as a “motivational magnet” (Berridge et al., 2010) that monopolizes attention and triggers lapses in diet adherence. Studies have consistently linked attentional biases toward food with obesity (Castellanos et al., 2009; Doolan et al., 2014; Hendrikse et al., 2015; Nijs, Franken, & Muris, 2010; Nijs, Muris, Euser, & Franken, 2010; Werthmann et al., 2011) and weight gain (Calitri, Pothos, Tapper, Brunstrom, & Rogers, 2010; Yokum, Ng, & Stice, 2011), however, there is a need for well-controlled studies that can determine whether these associations stem from stable individual differences in attentional processing, or a greater acquired salience for food cues among those prone to obesity.

Temporal discounting

Mechanistically, engaging in health behaviors often involves pursuing the more valuable, long-term rewards associated with wellness over immediate gratification from various temptations. This dynamic characterizes healthy eating and weight control (Appelhans,

2009; Epstein, Salvy, Carr, Dearing, & Bickel, 2010; Herman & Polivy, 2003), abstaining from substance use (Amlung & MacKillop, 2011; Audrain-McGovern et al., 2009; Bickel, Odum, & Madden, 1999; Fernie et al., 2013; Friedel, DeHart, Madden, & Odum, 2014; Green & Lawyer, 2014; Heil, Johnson, Higgins, & Bickel, 2006; Hoffman et al., 2006; Kirby & Petry, 2004; Kirby, Petry, & Bickel, 1999; Reynolds, Richards, Horn, & Karraker, 2004; Robles, Huang, Simpson, & McMillan, 2011; Vuchinich & Simpson, 1998) and risky sexual activity (Dariotis & Johnson, 2015; Herrmann, Hand, Johnson, Badger, & Heil, 2014; Johnson & Bruner, 2012; Jones & Sullivan, 2014), and other health behaviors (Axon, Bradford, & Egan, 2009; Bradford, 2010; Daugherty & Brase, 2010). Yet these choices are rarely straightforward, even for those who value their future health. Humans discount the value of future rewards relative to opportunities for immediate gratification, a process known as *temporal discounting*. Delayed rewards are discounted in value as a hyperbolic function of time such that the desire for a reward spikes just before it is received (**Figure 1**). As a result, an individual presented with the choice between two future rewards may initially prefer the more highly valued option, but experience a preference reversal if the less preferred reward becomes available immediately. Thus, temporal discounting accounts for “short-sighted” decisions that conflict with an individual’s long-term interests (Ainslie, 1975; Loewenstein, Read, & Baumeister, 2003).

Most dietary lapses can be interpreted as preference reversals (Appelhans, 2009; Epstein et al., 2010; Herman & Polivy, 2003). In general, the most palatable, rewarding foods are high in calories, fat, salt, and sugar, and are poor in nutrients (Drewnowski, 1995; Kessler, 2009), which places immediate gratification from food in direct opposition to healthy eating and weight control. A dieter generally prefers weight loss to food reward when both options are considered as future outcomes. However, relative to the point of decision, the weight loss benefits of individual food choices are perpetually perceived as occurring in the future, whereas gratification from food is immediate. The tendency to steeply discount future rewards is associated with higher body weight (Epstein et al., 2014; Fields, Sabet, Peal, & Reynolds, 2011; Jarmolowicz et al., 2014; Weller, Cook, Avsar, & Cox, 2008) and weight gain (Kishinevsky et al., 2012), and appears to contribute to overeating among those who are particularly sensitive to food’s rewarding properties (Appelhans et al., 2011a; Best et al., 2012; Rollins, Dearing, & Epstein, 2010).

Cold-hot empathy gap

“Hot” visceral states such as hunger, thirst, sexual arousal, and craving are characterized by increased *wanting* of stimuli (e.g., food, water, sexual stimulation, drugs) that can resolve these drives (Alcaro & Panksepp, 2011; Levy, Thavikulwat, & Glimcher, 2013). Yet humans have difficulty anticipating the often powerful effects of visceral states (including temptation) on their decisions and behaviors (Gilbert, Gill, & Wilson, 2002; Loewenstein, 1996). This inability to “empathize” with one’s self in a different visceral state plays out in two ways. The *hot-cold empathy gap* is apparent when individuals in a hot, motivated state overestimate the degree to which they will value a reward in a non-motivated, neutral, “cold” state. For example, individuals make less healthy food choices when hungry (a hot state) compared to when satiated (a cold state), even when choosing what to eat next week (Read & van Leeuwen, 1998).

Conversely, the *cold-hot empathy gap* describes the tendency of an individual in a cold state to underestimate the impact of future hot visceral states on their decisions and behavior. Just as hungry subjects *overvalue* foods that they will consume in the future, satiated subjects *underestimate* the value food will have to them in the future when they are hungry (Fisher & Rangel, 2014; Gilbert et al., 2002). Similar examples of cold-hot empathy gaps have been documented during sexual arousal (Ariely & Loewenstein, 2006), drug craving (Giordano et al., 2002; Sayette, Loewenstein, Griffin, & Black, 2008), and other visceral states (Van Boven, 2013). The cold-hot empathy gap is particularly relevant to weight management because it implies that dieters routinely overestimate their capacity to resist temptation.

Temptation management in hot versus cold states.

The hypothesized roles of attentional bias, temporal discounting, and the cold-hot empathy gap in dietary lapses are synthesized in **Figure 2**. The contribution of each process evolves over time as dietary lapses unfold. The cold-hot empathy gap precludes an individual from preparing for encounters with temptation before they occur, whereas attentional biases are thought to initiate and perpetuate the hot states that are associated with preference reversals and culminate in dietary lapses.

The shifting neurobehavioral profile of dieters from cold to hot (tempted) states underscores the importance of distinguishing between intervention strategies focused on resisting temptation while it is experienced, and those focused on avoiding temptation altogether. Strategies focused on resisting temptation are implemented by individuals when they are already in a hot state – in the “heat of the moment.” These *temptation resistance strategies* rely heavily on effortful inhibition, align with the lay concept of “willpower,” and include “urge surfing” [allowing cravings to pass without acting on them (Bowen & Marlatt, 2009; Forman & Butryn, 2015; Forman, Butryn, Hoffman, & Herbert, 2009)], “urge suppression” [inhibiting or ignoring a craving (Siep et al., 2012)], and cognitive reappraisal (Siep et al., 2012; Stice et al., 2015).

In contrast to temptation resistance strategies, temptation prevention strategies focus on *avoiding or minimizing* temptation. For example, stimulus control strategies involve identifying and modifying environmental factors that trigger problem behaviors, such as removing tempting foods from the home to prevent overeating (Butryn, Webb, & Wadden, 2011; Poelman et al., 2015). Other interventions emphasize scheduling and planning as strategies to manage temptation (Gillison et al., 2015; Kiernan et al., 2013; Murawski et al., 2009; Perri et al., 2001). The effectiveness of temptation prevention strategies may hinge on whether they are implemented in a cold state. For example, stimulus control strategies focused on ridding the home of tempting, unhealthy foods may be successful only to the extent that one is not tempted at the supermarket (Pagoto & Appelhans, 2015).

Both temptation resistance and prevention strategies are commonly featured in lifestyle interventions (Diabetes Prevention Program Research Group, 2002; Forman et al., 2009; Forman et al., 2007; Gorin et al., 2013; Poelman et al., 2015), however, their uptake and utilization by subjects and their impact on diet adherence (independent of the overall intervention package) have not been characterized. The nonresponse and relapse rates of

existing lifestyle interventions, in which these two classes of temptation management strategies are mainstream, suggest the need to systematically study and improve upon these approaches.

The role of executive functions in temptation management.

Thus far, we have distinguished temptation management strategies based on their intent of resisting versus preventing temptation, yet they can also be categorized based on the demand they place upon executive functions. Managing temptation represents an aspect of self-regulation (Ent, Baumeister, & Tice, 2015), which refers to psychological and behavioral processes that individuals utilize while actively pursuing goals, including health-related goals such as dietary modification and weight loss (Hall & Marteau, 2014; Mann, de Ridder, & Fujita, 2013; Rasmussen, Wrosch, Scheier, & Carver, 2006). Successful self-regulation, in turn, heavily depends on executive functions (Barkley, 2001; Hofmann, Schmeichel, & Baddeley, 2012), which are high-level, top-down cognitive processes that are critical for overriding “automatic” or default actions (Mesulam, 2002) and maintaining goal-directed behavior (Miller & Cohen, 2001).

Multiple competing models of executive function have been proposed, each varying in the number and types of distinct executive functions posited (Barkley, 2001; Cummings, 1995; Domenech & Koechlin, 2015; Jurado & Rosselli, 2007). However, at least some consensus exists around the notion of three core executive function domains (Diamond, 2013; Miyake et al., 2000). *Inhibitory control* refers to the effortful suppression of impulses at the behavioral, cognitive, and affective levels, and is essential for suppressing extraneous or unwanted thoughts, focusing attention on relevant stimuli, and curbing impulsive behaviors (Baumeister, 2014; Filevich, Kuhn, & Haggard, 2012; Munakata et al., 2011). *Working memory* represents the ability to hold and manipulate information “in one’s mind” (Baddeley, 2010), whereas *cognitive flexibility* refers to the ability to entertain alternative perspectives and anticipate future outcomes (Diamond, 2013). The three core facets of executive function interact heavily to support higher-order abilities such as planning, problem-solving, pursuing goals, reasoning, and monitoring progress based on feedback (Bechara, Damasio, Damasio, & Anderson, 1994; Diamond, 2013; Munakata et al., 2011). Executive functions are largely mediated by different regions of the prefrontal cortex and their cortical and subcortical connections with other neural networks (Banich & Depue, 2015; Coutlee & Huettel, 2012; Domenech & Koechlin, 2015; Linden, 2007; Miller & Cohen, 2001).

Temptation resistance strategies, which focus on overcoming temptation while in a hot state, are most directly related to the inhibitory control facet of executive function (Filevich et al., 2012; Munakata et al., 2011). Performance-based measures of inhibitory control, such as stop-signal and go/no-go tasks, are consistently associated with dietary intake and vulnerability to overeating and obesity (Ely, Winter, & Lowe, 2013; Hall, 2012; Hall, Lowe, & Vincent, 2014; Reinert, Po’e, & Barkin, 2013; Vainik, Dagher, Dube, & Fellows, 2013). One study involving undergraduate students found that hunger (a hot state) had a stronger effect on food choice among those with lower inhibitory control as measured by a stop-signal task (Nederkoorn, Guerrieri, Havermans, Roefs, & Jansen, 2009). Behavioral tasks

purported to measure inhibitory control engage prefrontal brain regions implicated in executive functioning (Criaud & Boulinguez, 2013; Simmonds, Pekar, & Mostofsky, 2008; Swick, Ashley, & Turken, 2011; Zandbelt, Bloemendaal, Hoogendam, Kahn, & Vink, 2013). Active suppression of cravings during exposure to palatable food cues, which is analogous to the intervention strategies “urge suppression” and “urge surfing,” also engages prefrontal brain regions commonly implicated in executive functioning (Siep et al., 2012; Yokum & Stice, 2013).

As temptation prevention strategies are implemented in a cold state and are aimed at circumventing rather than resisting temptation, they are (almost by definition) not reliant on inhibitory control. Instead, temptation prevention strategies may recruit the working memory and cognitive flexibility components of executive function, which support higher level abilities such as problem-solving, planning, and goal pursuit. For example, stimulus control strategies require prospective thinking to identify and avoid exposure to foods that may challenge future self-control (Seligman, Railton, Baumeister, & Sripada, 2013). Another temptation management approach involves identifying adaptive behavioral responses through structured problem-solving exercises, which invoke reasoning and divergent thinking abilities within the working memory and cognitive flexibility domains (Diamond, 2013; McClure & Bickel, 2014). Relatively few studies have examined associations between working memory or cognitive flexibility measures and diet- or obesity-related outcomes, and published associations have been less consistent than with inhibitory control (Vainik et al., 2013).

Executive functions, particularly within the inhibitory control domain, are notoriously susceptible to disruption by a host of factors commonly encountered in daily life (Heatherton & Wagner, 2011; Hofmann et al., 2012). Performance on tests of executive function or self-control decline with exposure to stress (Pabst, Schoofs, Pawlikowski, Brand, & Wolf, 2013; Tryon, Carter, Decant, & Laugero, 2013), increased cognitive demands (Gathmann, Pawlikowski, Scholer, & Brand, 2014; Gunn & Finn, 2015; Hinson, Jameson, & Whitney, 2003; Starcke, Pawlikowski, Wolf, Altstotter-Gleich, & Brand, 2011), and insufficient sleep (Reynolds & Schiffbauer, 2004; Rossa, Smith, Allan, & Sullivan, 2014; Whitney & Hinson, 2010). Even more troubling are studies suggesting that executive functions often fail when they are needed most, such as during “hot” states characterized by visceral arousal (Ariely & Loewenstein, 2006; Loewenstein, 1996; Metcalfe & Mischel, 1999) or with mere exposure to a tempting stimulus (Hagger et al., 2013; Heatherton & Wagner, 2011). Inhibitory control may also be subject to fatigue or depletion such that the act of exercising inhibitory control reduces inhibitory strength in subsequent situations (Hagger, Wood, Stiff, & Chatzisarantis, 2010; also see Carter & McCullough, 2014). Virtually all of the factors that have been shown to interfere with executive functioning have also been implicated as triggers of overeating or dietary lapses in laboratory or clinical studies (Beebe et al., 2013; Harris, Bargh, & Brownell, 2009; Houben, Nederkoorn, & Jansen, 2012; Markwald et al., 2013; Torres & Nowson, 2007; Ward & Mann, 2000; Zimmerman & Shimoga, 2014). Interpreted through the lens of dual-system models in which executive/inhibitory and impulsive/appetitive systems vie for control of behavior (Appelhans, 2009; Bechara, 2005; Bickel, Jarmolowicz, Mueller, Gatchalian, & McClure, 2012; Evans & Stanovich, 2013; Hall & Fong, 2007; Hall & Fong, 2010; Heatherton &

Wagner, 2011; Jentsch & Taylor, 1999; Strack & Deutsch, 2004), transient disruptions of executive function disinhibit the appetitive system, resulting in impulsive behaviors including dietary lapses. Incorporating temptation management strategies that are robust to executive function disruptors could greatly improve diet adherence in the context of lifestyle interventions, particularly for those with intrinsically low levels of executive function or who are exposed frequently to executive function disruptors in daily life.

Addressing executive function disruptors in lifestyle interventions

Two themes dominate the literature on how to improve temptation management approaches. One theme focuses on enhancing executive functions. For example, inhibitory control training and computerized working memory training programs have shown promising effects for reducing laboratory food intake or impulsive choice (Bickel, Yi, Landes, Hill, & Baxter, 2011; Houben & Jansen, 2011, 2015). Other groups are exploring rehearsal of episodic prospection (imagining future experiences) to reduce impulsivity, also with promising preliminary results (Daniel, Said, Stanton, & Epstein, 2015; Daniel, Stanton, & Epstein, 2013a, 2013b; Lin & Epstein, 2014; Peters & Buchel, 2010; Radu, Yi, Bickel, Gross, & McClure, 2011). Additional research is needed to determine if these benefits are long-lived and translate into sustained behavior change in real-world settings.

The other major theme in the literature calls for greater incorporation of strategies that are minimally dependent on executive function, and therefore unaffected by executive function disruption. Regulatory approaches (e.g., taxing sugar-sweetened beverages) (Farley, 2012; Novak & Brownell, 2012) and “choice architecture” interventions that use contextual manipulations to nudge behavior (Hollands et al., 2013; Levy, Riis, Sonnenberg, Barraclough, & Thorndike, 2012; Skov, Lourenco, Hansen, Mikkelsen, & Schofield, 2013; Thorndike, Riis, Sonnenberg, & Levy, 2014) are both motivated by the desire to avoid or minimize temptation without relying on individuals’ executive functions. However, these approaches are implemented by external agents and are not germane to lifestyle interventions. In contrast, some lifestyle interventions include *commitment strategies*, which are mechanisms that enable individuals manage temptation by voluntarily constraining his or her *own* future choices (thus commitment is a form of *self-regulation*). Two varieties of commitment strategies are commonly distinguished. *Strict commitment* involves constraining one’s future choices to more valuable, delayed rewards (Rachlin, 2000). Examples of strict commitment include enrolling in residential addiction and obesity treatment programs that limit one’s access to temptations (Kelly & Kirschenbaum, 2011; Reif et al., 2014), or placing temptations (e.g., junk food, cigarettes) in time-locking safes that open only after an extended delay (www.thekitchensafe.com).

Strict commitment is not always feasible in the real world as placing irrevocable constraints on one’s own behavior is logistically difficult (non-institutionalized adults can usually opt out of prior commitments to themselves). For this reason, most real-world commitment strategies work not by rigidly constraining future choices, but by attaching a cost to impulsive choices. Such *commitment by punishment* involves pairing temptations with some form of punishment, such as a financial penalty or loss of time, in order to minimize temptation at the point of decision (Green & Rachlin, 1996). A classic example of

commitment by punishment is the medication disulfuram (Antabuse), which reduces the allure of alcohol at the point of decision by inducing a highly aversive reaction when it is consumed (Bell & Smith, 1949). Another commonly utilized commitment by punishment strategy involves financial contracting, whereby an individual enters into a binding agreement to forfeit an amount of money if they fail to meet a specified behavioral goal (Halpern, Asch, & Volpp, 2012). Financial contracting for weight loss has been found effective in a number of studies (Forster, Jeffery, Sullivan, & Snell, 1985; Jeffery, 2012; Jeffery, Bjornson-Benson, Rosenthal, Lindquist, & Johnson, 1984; John et al., 2011; Kullgren et al., 2013). Similarly, social contracting may involve publicly committing to a behavioral goal, thereby exposing one's (future) self to embarrassment before family and friends if temptation prevails (Rieger et al., 2014). Both forms of commitment enable "cold" individuals to make a better choice for their future selves by bypassing or minimizing temptation, obviating the need to exercise inhibitory control strategies that are prone to disruption (Marteau, Hollands, & Fletcher, 2012).

To date, most applications of commitment to obesity treatment have involved financial contracting (Halpern et al., 2012; Rogers, Milkman, & Volpp, 2014; Schwartz et al., 2014). Some published interventions have included components that, while not explicitly described as such, capitalize on the principle of commitment. For example, several interventions have incorporated home-delivery of healthy meals (Appelhans et al., 2013; Gorin, Raynor, Niemeier, & Wing, 2007), which allows individuals in a cold state to make healthier food choices for their future selves (Hanks, Just, & Wansink, 2013; Milkman, Rogers, & Bazerman, 2010). The development of novel commitment strategies that support diet adherence represents an exciting and potentially fruitful undertaking.

A two-dimensional model of temptation management

Based on the foregoing considerations, we propose a two-dimensional framework for classifying temptation management strategies according to their intended effects on reward processing (Table 1, organized horizontally) and the dependence of each strategy on executive functions (Table 1, organized vertically). The top row of Table 1 includes the temptation resistance and prevention strategies that are common in existing lifestyle interventions. Temptation resistance strategies are implemented by an individual in a hot state with the goal of *resisting* temptation, whereas temptation prevention strategies are implemented in a cold state with the aim of *avoiding or minimizing* future temptation. Both strategies are dependent on executive functions, with temptation resistance strategies most heavily invoking inhibitory control and temptation prevention strategies relying on working memory and cognitive flexibility. The second row of Table 1 lists examples of commitment strategies that enable individuals to either avoid/minimize or resist temptation while placing minimal demands on executive function. Individuals must only initiate or enroll in these interventions (while in a cold state), rather than apply strategies independently in daily life. The bottom row of Table 1 includes regulatory strategies and choice architecture interventions that are implemented by external agents and require virtually no executive function involvement on the part of the individual.

Conclusions and Future Directions

The two-dimensional model of temptation management offers a conceptual framework for systematically selecting temptation management strategies for inclusion in lifestyle interventions. The neurobehavioral profile of temptation, combined with exposure to factors that disrupt executive function, preclude success in managing temptation through resistance alone for most dieters. Temptation prevention strategies can avoid or minimize exposure to temptation, but these strategies are also sensitive to executive function disruption and can only be applied to temptations that are anticipated in advance. Existing lifestyle interventions generally include some combination of temptation prevention and resistance strategies, and their high rates of nonresponse and relapse provide a motive for the field to either bolster these strategies against executive function disruptors, or explore the value of integrating commitment strategies that depend only minimally on executive functions. Lifestyle interventions seeking to incorporate a comprehensive approach to temptation management would include strategies that complement each other in terms of their intended effects on reward processing and executive function demands (the top four cells of Table 1).

Our review identified several gaps in the scientific literature on temptation management. The temptation management strategies included in most lifestyle interventions have not been systematically evaluated independent of other treatment components. As a result, their uptake, implementation, and effectiveness remain uncertain. This information is critical to refining temptation management approaches, and ultimately, to improving lifestyle interventions more generally. Studies that test utilization of specific temptation management strategies as mediators of weight loss outcomes, and directly compare different temptation management approaches in populations of interest (e.g., treatment nonresponders, those with low executive function or high sensitivity to food reward) would be particularly valuable towards this end.

Research on temptation management is currently hindered by a lack of reliable and valid measurement approaches. Use of individual temptation management strategies might be measured in multiple formats, including behavioral response/choice tasks where subjects “play” for access to immediate and delayed rewards, self-report instruments, ecological momentary assessments, or with systems for objectively monitoring the use of commitment devices. Regardless of format, such measures would be most useful when adapted to specific contexts (e.g., temptation from high-calorie foods). The availability of appropriate measurement tools could help answer several high-priority research questions, such as:

- Which temptation management approaches are most modifiable through intervention?
- Do individuals have stable preferences for temptation resistance versus prevention strategies, and are such preferences predictive of successful weight loss?
- Is an individual’s willingness to apply commitment strategies contingent on their recognition of their vulnerability to temptation (overcoming the cold-hot empathy gap)?

Tailoring the delivery of temptation management strategies based on key individual difference variables may improve success rates in lifestyle interventions. Individuals vary substantially in their food reward sensitivity (Epstein et al., 2007), intrinsic executive

functioning capacities (Braver, Cole, & Yarkoni, 2010), and exposure to various executive function disruptors. Given valid measures of these factors, it would be possible to tailor temptation management approaches to match individuals' neurobehavioral profiles. For example, one of us (NES) is currently examining whether the provision of healthy meals (an example of commitment) has greater benefits for diet adherence and weight loss among individuals who are non-responders to weight loss treatment and score lower on neuropsychological tests of executive function. Temptation management approaches could also be tailored based on treatment response. For example, an adaptive intervention may initially emphasize traditional temptation resistance and prevention strategies, and reserve alternative strategies with lower executive function demands but potentially greater costs (e.g., commitment devices) for non-responders or those prone to relapse. Sequential multiple assignment randomized trial (Almirall, Nahum-Shani, Sherwood, & Murphy, 2014) and fractional factorial (Collins, Dziak, Kugler, & Trail, 2014) study designs would be useful for identifying appropriate sequences and combinations of temptation management strategies.

An exciting array of innovations in temptation management is on the horizon. Interventions that enhance individuals' executive function and self-regulatory skills are now being explored (discussed above). New variants of commitment are also being explored. For example, Rachlin's (2000) "soft commitment" involves grouping choices or behaviors into long-term patterns (rather than constraining them) so that any single opportunity to succumb to immediate gratification is considered part of a temporally-extended trend that is less vulnerable to discounting effects (Myrseth & Fishbach, 2009; Rachlin, 2000; Rogers & Bazerman, 2008). Choices can be grouped through various mechanisms, such as adopting "personal policies" (e.g., "I never snack after 7:00 PM"), or making decisions in sets in advance of consumption (e.g., planning a week's worth of meals in advance). Choices can also be grouped through "pattern setting" (Rachlin, 2015) which involves yoking one's future consumption of a temptation to that at a particular instance. For example, rather than directly attempting to reduce one's soda intake, a dieter could commit to always consuming the same amount of soda on weekdays as he or she does the prior Sunday. Reductions in soda intake would be expected over several weeks, not because the individual is striving to limit soda consumption, but because beverage choices on Sundays acquire significance as setting a precedent for future consumption. Human laboratory studies support hypothesized effects of soft commitment on decision-making and behavior (Camilleri & Newell, 2013; Myrseth & Fishbach, 2009; Read, Loewenstein, & Rabin, 1999), but more research is needed to determine whether this approach translates as an effective obesity intervention strategy.

Technology may inspire new directions in temptation management. Mobile technology could allow interventionists to provide real-time support to individuals during hot states, or enable the development of new, more feasible commitment devices. For example, smartphone-based payment methods could be harnessed to enable individuals to block their ability to purchase fast food, online social networks could serve as forums for people to make public or financial commitments (e.g., DietBet.com), and mobile applications used to arrange transportation could allow an individual to commit to traveling to the gym immediately after work on certain days. Such approaches would not have been possible even 5 years ago, and the present may be an ideal time for innovation in temptation management.

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Figure 1.

Due to hyperbolic temporal discounting, an individual's preference for a large, delayed reward (e.g., weight control) can reverse if a smaller but immediate reward (e.g., dessert) becomes available. These preference reversals (occurring at the intersection of the two valuation curves), are characteristic of impulsive, short-sighted decisions.

Figure 2.

Diagram of dietary lapses under temptation. Encountering palatable food cues elicits enhanced attentional focus on food, and “hot” visceral states associated with a preference for immediate gratification. Due to the cold-hot empathy gap, individuals have difficulty appreciating these changes in advance. It is as though multiple selves (current and future) with competing priorities and different behavioral tendencies exist within the same individual at different times. Different sets of temptation management strategies are likely to be effective in cold versus hot states.

Table 1

Two-dimensional model of temptation management. Representative examples of temptation management strategies are listed according to their intended impact on reward processing (organized horizontally) and the demands that each strategy places on executive functions (organized vertically).

Demand on executive functions	Intended impact on reward processing	
	Prevent temptation	Resist temptation
High: Individuals are trained to apply strategies independently	<ul style="list-style-type: none"> • Stimulus control • Home environment restructuring • Problem-solving 	<ul style="list-style-type: none"> • Urge surfing • Urge suppression • Working memory training • Episodic prospection
Minimal: Commitment; individuals initiate or enroll in interventions	<ul style="list-style-type: none"> • Strict commitment <ul style="list-style-type: none"> - Immersive therapies (residential programs) - Pre-ordering healthy foods 	<ul style="list-style-type: none"> • Commitment by punishment <ul style="list-style-type: none"> - Financial contracting - Social contracting
None: Regulatory or choice architecture interventions enacted by external agents	<ul style="list-style-type: none"> • Choice restriction • Contextual “nudges” 	<ul style="list-style-type: none"> • “Sin taxes” on less healthy, but more tempting choices