The Dynamics of Goal Revision: A Cybernetic Multiperiod Test-Operate-Test-Adjust-Loop (TOTAL) Model of Self-Regulation

Author(s): Chen Wang and Anirban Mukhopadhyay

Source: *Journal of Consumer Research*, Vol. 38, No. 5 (February 2012), pp. 815-832
Published by: The University of Chicago Press
Stable URL: http://www.jstor.org/stable/10.1086/660853

The Dynamics of Goal Revision: A Cybernetic Multiperiod Test-Operate-Test-Adjust-Loop (TOTAL) Model of Self-Regulation

CHEN WANG
ANIRBAN MUKHOPADHYAY

This research presents a comprehensive conceptual model of the dynamics of goal revision over multiple periods. First, based on an integrative literature review, we derive four principles that govern how individuals update their goals over time (monotonicity, diminishing sensitivity, aspiration maximization, and performance satisficing). We then integrate these principles logically as well as mathematically into a goal-discrepancy response function. Next, we advance existing cybernetic models of self-regulation by synthesizing the four principles and the response function into a Test-Operate-Test-Adjust-Loop (TOTAL) model, which captures the dynamics of goal revision in self-regulation. We report four laboratory experiments that demonstrate initial support for the postulates of our model and conclude with a discussion of limitations and future directions.

A goal is defined as a "wished-for end that is considered to be attainable" (Geen 1995), and it is well accepted that people set goals to motivate themselves toward desired ends (Austin and Vancouver 1996; Locke and Latham 1990; Soman and Cheema 2004; Vohs, Baumeister, and Tice 2008). As they strive toward their goals after setting them (Bagozzi and Dholakia 1999; Thaler and Shefrin 1981), people may recalibrate the original goal, representing an adjustment in the wished-for end. Sometimes the shift is upward. For example, someone who sets and then achieves a goal to run 5 miles in an hour may then aim higher, and strive to run 6 miles instead. Such an adjustment reflects a reaction to an insufficient challenge; a wished-for end that was previously not attainable has now been reached and is therefore supplanted by a higher level of aspiration. In contrast, sometimes the shift may be downward. For instance, another person may find it impossible to run for an hour at a time and therefore may downgrade their goal to 45 minutes. Such an adjustment indicates a goal beyond reach and results in a less demanding target. Either way, many common activities involve similar dynamic revisions of goals across multiple time periods.

Existing research in goal-directed behaviors has primarily focused on how people strive toward a single goal that remains fixed during a single period (Austin and Vancouver 1996; Carver and Scheier 1981; Gollwitzer 1999; Locke and Latham 1990). Indeed, much is now known about the rate of progress or goal velocity given a static goal (Fishbach and Dhar 2005; Fishbach, Dhar, and Zhang 2006; Kivetz, Urminsky, and Zheng 2006; Soman and Shi 2003; Zhang and Huang 2010), the implications of goal conflict (Emmons and King 1988; Riediger and Freund 2004; Schmuck and Sheldon 2001), and even the dynamics of multiple-goal pursuit (Louro, Pieters, and Zeelenberg 2007). However, these all assume that the goal standard is static. A second area that has attracted attention of late is the interaction between

Chen Wang is a doctoral student in marketing at the Sauder School of Business, University of British Columbia, Vancouver, BC, Canada V6T 1Z2 (chen.wang@sauder.ubc.ca). Anirban Mukhopadhyay is associate professor of marketing at the Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong (anirban.mukhopadhyay@ust.hk). Both authors contributed equally to this article, and correspondence may be directed to either. The authors thank the editor, associate editor, three reviewers, Darren Dahl, Juliano Laran, Jaideep Sengupta, Rongrong Zhou, Juliet Zhu, and especially Jiewen Hong and Ralf van der Lans for their helpful comments on previous drafts. This research was supported by grants from the Hong Kong Research Grants Council (CERG HKUST 642810 and DAG_S09/10 BM06) to the second author.

Ann McGill served as editor and Steve Hoch served as associate editor for this article.

Electronically published June 13, 2011

 ● Vol. 38 ● February 2012
 0093-5301/2012/3805-0004$10.00. DOI: 10.1086/660853

multiple conflicting goals (Fishbach and Dhar 2005; Fishbach, Zhang, and Koo 2009; Laran 2010a, 2010b; Laran and Janiszewski 2009; Mukhopadhyay and Johar 2009; Mukhopadhyay, Sengupta, and Ramanathan 2008). While these researchers do generally consider behavior across multiple episodes, the focus is on the interplay between the different goals, rather than how a single goal is updated over time. Moreover, this body of research on multigoal pursuit also assumes that goals once set are static—a person who has a goal of healthiness maintains that goal at a constant level across time and allocates resources toward and away from it depending on contextual and individual difference factors, and inferences about progress and commitment. Most telling, perhaps, is Baumgartner and Pieters's (2008) comprehensive review chapter that addresses nearly every aspect of goal setting and striving, including goal selection, setting, planning, monitoring, and plan revision. The one notable omission in this overview is the idea that the extent of progress toward a goal at time 1 can influence the level of the goal set at time 2—that is, the dynamics of goal setting.

Much research implicates accurate goal setting as being critical to successful self-regulation (Gollwitzer 1999; Vohs et al. 2008), and hence it is extremely important for consumer behavior to understand how goals for a new time period are revised based on previous performance and feedback. The main aim of this research is to integrate existing knowledge about goal-directed behavior to offer a comprehensive theoretical model of goal updating in a multiperiod context. In what follows, we first review the literature and derive four principles that dictate dynamic goal setting across multiple periods. We then integrate these principles by extending existing cybernetic models of goal-directed behavior (Carver and Scheier 1981; Miller, Galanter, and Pribram 1960). We do this in two ways—conceptually as well as mathematically. This represents the formal development of our model. We then present four experiments that serve as an initial test of the model and help estimate its parameters. Finally, we conclude with a discussion of several directions for future research that are suggested by the model.

GENERAL PRINCIPLES GOVERNING GOAL UPDATING

The focus of our investigation is on goals that are dynamic and iterative. In such situations, people establish certain reference standards (or "goals"; as per Carver and Scheier 1981). We propose that for goals that are pursued across multiple periods, people may adjust their goals in subsequent time periods based on their performance. The key question is, how exactly do they revise their goals? We turn to the goals literature and identify four general principles that apply in such situations.

We take as our point of departure the basic principle that goal-directed behavior consists of two distinct phases—goal setting and goal striving (Bagozzi and Dholakia 1999; Thaler and Shefrin 1981). Much research addresses the processes that drive each of these two phases (see Baumgartner and Pieters [2008] for a review). However, as noted above, there is little or no indication in the literature that goal striving can influence goal setting (or re-setting). What the extant literature does accommodate very well, however, is the idea that goal striving can feed back on itself. In other words, people monitor the extent of their progress toward their goals and adjust the rate of progress and effort inputs, if required. We first explicate this idea, which derives from the principles of cybernetic control theory, and then discuss how it may be modified, in terms of how goal striving can iteratively feed back to the previous phase of goal setting.

Cybernetic Models of Self-Regulation

The driving philosophy behind most models of self-regulation is that of a dual process system (Carver and Scheier 1981, 1998; Karoly 1993; Miller et al. 1960; Powers 1973; Tsui and Ashford 1994; Wegner 1994). This system consists of two interlinked mechanisms, namely, a "higher order" mechanism that exerts control over a "lower order" mechanism. The functioning of the higher order monitoring mechanism is often likened to that of a thermostat, which is programmed to start a heating element (here the lower order operation) if the temperature falls below a certain level, and to stop it if the temperature rises above a certain level. In this case, one system performs the actual heating, and the other one monitors its performance against some set standards of temperature. The monitoring function is driven by a feedback loop consisting of four elements (MacKay 1966; Miller et al. 1960; Powers 1973; Wiener 1948), namely, an input function, a reference value, a comparator, and an output function. In general, the core view of this class of models is that the output function is aimed at reducing any discrepancy between the current state (i.e., the input function) and the desired goal (the reference value). The discrepancy-reducing loop (also called the negative feedback loop) works as follows. First, the monitoring system *tests* against a standard. If the comparison yields "no difference" between the input and the reference value, the output function remains as it was. This may mean either that the output is zero if there was no output before, or that it maintains the original value. If the comparison detects any discrepancy between the input and the reference value, the output changes accordingly. If the test is negative, an *operation* is performed. In this case, the operation would be to raise or lower the temperature. The *test* is then performed again. If it is still negative, the cycle loops back. Otherwise, if there is no discrepancy, it *exits*. It is evident why this general class of model is known as a TOTE model—the acronym stands for Test-Operate-Test-Exit (Miller et al. 1960).

Dual process models of self-regulation function in much the same way. We take as our example the Carver and Scheier model (henceforth, the "CS model"; Carver and Scheier 1981, 1998), which is representative of this class of models. The CS model construes self-regulatory behavior in terms of feedback control processes. Exactly as in cybernetic control theory (Miller et al. 1960), the model sug-

gests that people monitor the discrepancy between their current state and a desired end state, and that goal-directed behaviors are aimed at reducing such discrepancies (see fig. 1*A*; fig. 1*B* is introduced later). The input function here refers to perception, which brings information into the system. The reference value is equivalent to a goal or a desired end state. The comparator is a mechanism that compares the input information to the reference value, determining the extent of discrepancy. The result of the comparison is an output function that aims to reduce the discrepancy between the input and the reference value. This effect would be observed in behavior such as the attempt to attain a desired goal or to conform to a standard. For example, consider Wally, a normal person who would like to lose some weight. Wally starts out by first establishing a goal; for instance, he might tell himself that he has to "lose 20 pounds." He then proceeds to exert effort, by dieting and exercising. He monitors his behavior regularly by assessing the change in his weight, and compares the change to the goal standard. Eventually, Wally reaches his 20 pound weight loss target, then relieves himself of his diet and exercise commitments. (As Polivy and Herman's [2002] review soundly concludes, most people who lose weight end up putting it back on.)

The strength of the TOTE models, as may be evident from the example of Wally, lies in their elegance and parsimony. However, this anecdote also points up their evident limitations: What happens if Wally, a few days into his program, realizes that losing 20 pounds is just too difficult a task for him? Conversely, what if he had set a goal of losing 5 pounds and realized that he would be able to achieve the goal within 2 weeks? The TOTE models are not entirely clear on this point. In the former case, they would predict either that Wally may continue striving for an unattainable goal, or that he may disengage. In the latter case, they would predict that he will achieve his too-achievable goal and feel good about it, but do not shed any light on whether he would change his goal while in progress, or set a new goal once he had achieved the current one. Importantly, in either case, Wally's current goal is sacrosanct. Once set, the TOTE models do not allow for the possibility that an individual in the course of self-regulation may concurrently adjust his or her goals either upward or downward, or disengage. However, as Lord and Hanges (1987) point out, as people accumulate experience in a domain, they frequently adjust the expected pacing of their progress (see also Kivetz et al. 2006). This adjustment may be either upward or downward, depending on the experience. This is the key point of our research. As feedback on progress comes in, rather than merely wait for the system to *exit* based on a previously set, currently operative, goal, individuals may dynamically adjust their goal targets based on the feedback. To summarize, our purpose is to extend the TOTE models to the case of multiple periods with flexible goals and feedback—in effect, we propose a TOTAL, or Test-Operate-Test-Adjust-Loop, model of multiperiod goal revision.

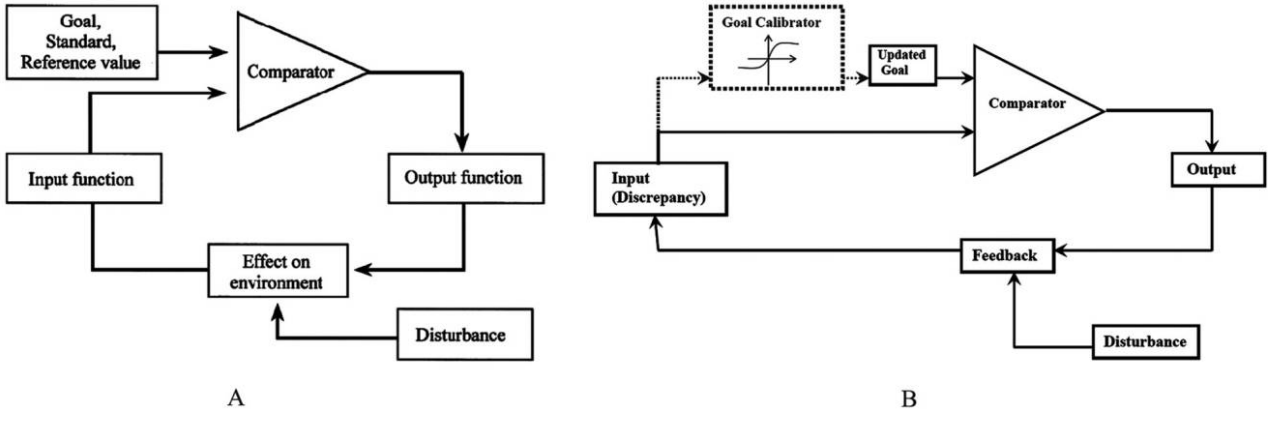
How Goals Are Revised: Four Principles

How might goals be revised based on goal-performance discrepancies? We now review extant research on multiperiod self-regulation and derive four general principles that drive the effects of discrepancies on goal revision across periods. Having derived these principles, we will propose how they may simultaneously be integrated into a general cybernetic TOTAL model.

Monotonicity. The first principle of goal revision is the simplest. It addresses the relationship between the magnitude of the discrepancy and the extent of goal revision. Simply put, this relationship is positive. This is because success at goal attainment increases perceptions of self-efficacy and increases self-perceptions of ability (Bandura and

FIGURE 1

(A) TOTE MODEL REPRESENTED BY CARVER AND SCHEIER'S DISCREPANCY-REDUCING MODEL AND (B) REVISED TOTAL MODEL FEATURING THE GOAL CALIBRATOR



Schunk 1981; Tolli and Schmidt 2008). Some of the best evidence on this matter comes from longitudinal studies of athletic performance. Donovan and Williams (2003) investigated data from 100 athletes, encompassing instantaneous goals (i.e., those relating to a given competition) as well as more enduring seasonal goals. In both cases, they found that the discrepancy between goals and performance had a significant positive effect on goal revision. Better performances led to higher targets, for the season as well as competition, and worse performances to correspondingly lower targets. Ilies and Judge (2005) studied repeated goal setting in creativity-based tasks and found the exact same pattern—small discrepancies led to small amounts of goal revision, and large discrepancies to larger amounts of goal revision. Based on this, we propose the principle of *monotonicity*, which posits that individuals experiencing goal-performance discrepancies tend to revise their goals in proportion to the magnitude of the discrepancies.

The term *monotonicity* as we use it is also known as "weak" proportionality. In contrast, "strict" proportionality would imply a stronger, possibly linear, relationship. As the next proposition will make clear, this implication is not supported by the evidence in the literature.

P1: *Monotonicity*: The magnitude of the goal revision is monotonically related to the magnitude of the goal-performance discrepancy.

Diminishing Sensitivity. The second principle addresses the boundedness of goal revision. Goal standards have boundaries, and the lowest effort inputs are usually observed when the task is either very easy or very hard (Atkinson 1958). Essentially, although people may shift their goals upward or downward, these operate within limits—of feasibility as well as desirability. As mentioned, a goal is "a wished-for end that is considered to be attainable" (Geen 1995, 23), which means that people set goals if they expect to be able to achieve them (Latham and Locke 1991; Tolman 1932). Therefore, at the upper margin, there must exist a limit beyond which, despite any amount of effort, the task is clearly beyond one's ability, despite any amount of motivation and opportunity (Brehm and Self 1989). Correspondingly, there must exist a lower limit beneath which disengagement occurs, as expectancies become more and more negative (Carver and Scheier 1998; Seligman 1975). As Carver and Scheier (1998, 189) put it, "Disengagement is an absolute necessity. It's a natural and indispensable part of self-regulation. If people are ever to turn away from efforts at unattainable goals, if they're ever to back out of blind alleys, they must be able to disengage, to give up and start over somewhere else."

To realize these upper or lower boundaries, each new unit discrepancy should deliver a smaller amount of additional utility (or disutility) in goal revision than the unit before. In other words, people should be decreasingly sensitive to the discrepancy as it gets larger. This proposition is supported by the insight that the sensitivity to changes along a particular dimension is reduced as the magnitude of the dimension increases (Torgerson 1958) as well as by the common assumption in economics that value functions are concave. For example, a consumer who has a goal of saving $110 is likely to be less sensitive to having saved $120, representing a discrepancy of $10, than if their goal had been to save $10 and they had actually saved $20. In effect, goals are not revised in an unlimited manner, but rather asymptotically extend toward certain upper as well as lower boundaries. Hence, the principle of *diminishing sensitivity* suggests that discrepancies should have a smaller marginal impact as they become larger.

P2: *Diminishing sensitivity*: Discrepancies that are larger in magnitude have a relatively smaller marginal impact on goal revision than do discrepancies that are smaller in magnitude.

Intrinsic versus Extrinsic Motivation. Having characterized the properties that are common to all goals, our next two principles address the distinct features of two different types of goals. According to self-determination theory (Deci and Ryan 1985), goals can be distinguished based on motivation orientation. *Intrinsically motivated goals* refer to goals that are generated for their inherent satisfactions rather than for some separable consequence. For example, personal growth, close relationships, and physical health are considered to be intrinsic (Kasser and Ryan 1996). When intrinsically motivated, a person is moved to satisfy basic and inherent psychological needs. In contrast, *extrinsically motivated goals* refer to goals that are pursued due to rewards that are separable from the activity itself. People pursue extrinsic goals to avoid penalty or gain external approval. Intrinsic and extrinsic motivation are not completely dichotomous. Rather, they represent two ends of a continuum ("the Self-Determination Continuum": Deci and Ryan 1985), representing the degree to which the motivation for one's behavior emanates from the self (Ryan and Deci 2000a, 2000b). As such, whether a goal is categorized as intrinsic or extrinsic depends on its location on the continuum, that is, the extent of the individual's self-determination toward the goal. This distinction is parallel to Austin and Vancouver's (1996) classification of goals as "internal" and "external," depending on the locus of the primary motivating factors. Further, the theoretical distinction between intrinsic and extrinsic motivation may be evidenced by a range of related constructs, such as involvement, goal importance, and self-relevance (Rogers, Kuiper, and Kirker 1977; Slama and Tashchian 1985; Trope and Pomerantz 1998). For example, Kasser and Ryan (1996) found, consistent with the theoretical distinction, that intrinsic goals, which were higher in self-determination, were indeed more important than extrinsic goals. It is worth noting, however, that self-determination is not equivalent to how much individuals care about their performance. For example, it is possible for someone to care equally about their performance for reasons that are intrinsic (e.g., pleasure) as well as extrinsic (e.g., monetary incentive).

Due to the difference in motivation, people respond differently to these two types of goals, and hence goal-setting

behaviors should also be different. In support of this proposition, Laran and Janiszewski (2011) find that extrinsically motivated tasks are depleting and lead to lower subsequent self-control, while intrinsically motivating tasks are vitalizing and lead to higher subsequent self-control. Thus, we consider the two separately in our analysis, and indeed our review of the literature indicates distinct principles that drive goal revision for intrinsically versus extrinsically motivated goals.

Aspiration Maximization. The pursuit of intrinsically motivated goals is inherently enjoyable and satisfying. The successful attainment of an intrinsically motivated goal leads to enhanced feelings of competence and thereby even greater levels of intrinsic motivation (Deci 1975). After people successfully attain an intrinsically motivated goal, they are likely to become more ambitious by aiming even higher in the next round of goal pursuit (Locke and Latham 2002). For example, Novemsky and Dhar (2005) demonstrated in the domain of gustatory indulgence that a good first experience (e.g., a good entrée) produces an upward shift in the target level of a sequential choice (e.g., a good dessert). Hence, success should lead to a desire for higher levels of attainment in the future. In contrast, we predict that responses to failure should be relatively more sticky. This is because intrinsically motivated goals are inherently desirable and are set because the goal setter is inherently motivated to attain them. They also tend to be more basic and more important, and hence more likely to be persisted with in the face of failure (Deci and Ryan 2000). In support of this proposition, Donovan and Williams (2003) found that athletes who failed to reach their goals revised their goals only slightly downward, and indeed Brunstein and Gollwitzer (1996) found that students who failed at a task relevant to their professional self-definition performed at an even higher level on a subsequent task relevant to the same self-definition. This suggests that when people are intrinsically motivated toward a goal, they are averse to lowering their standards, even if they have failed in the past. Labeling this the "False Hope Syndrome," Polivy and Herman (2002, 678) aver, "having failed, they interpret their failure in such a way that the failure is seen as far from inevitable; people convince themselves that with a few adjustments, success will be within their grasp." Based on this discussion, we propose the principle of *aspiration maximization*, according to which a positive goal-performance discrepancy for an intrinsically motivated goal should lead to a significant upward revision, but, in contrast, a negative discrepancy should lead to relatively smaller downward revision, if at all. More formally,

P3: *Aspiration maximization*: For intrinsically motivated goals, positive discrepancies lead to significant upward revisions, whereas negative discrepancies lead to relatively small downward revisions.

Performance Satisficing. A different pattern of behavior should obtain for extrinsically motivated goals. Here, people respond to success and failure in very different manners. Recall that extrinsically motivated goals are pursued for the sake of external awards as opposed to inherent satisfactions. As a result, if the incentives are linked to goal attainment (as they usually are, as opposed to overattainment or the extent of surplus), people may not desire to improve on their performance when progress is going well. Rather, as Simon (1953, 1955) speculated, given an extrinsically motivated goal with the explicit instruction to do their best, people may instead "satisfice," that is, settle for a level of achievement that is merely adequate. This logic similarly dictates that responses to failure or lack of progress should also be correspondingly different. If attainment is the only outcome of interest, then settling for an adequate level of achievement essentially implies downgrading the target to one that is expected to be comfortably achieved. As a result, negative discrepancies should see significant downward adjustments in response.

In support of these propositions, Ilies and Judge (2005) found that when asked to perform tasks such as word listing and the remote associates test, which were clearly experimental tasks of no intrinsic value, participants adjusted their goals downward following negative feedback. Conversely, participants were easily satisfied with any achievement and, rather than revise their targets upward, preferred to maintain the original goal even when there was a positive discrepancy. This pattern is due to the extrinsic nature of the motivation in these tasks—there was no incentive to exceed the given goals. Hence, the principle of *performance satisficing* posits that a negative goal-performance discrepancy for an extrinsically motivated goal should lead to a significant downward revision, whereas a positive discrepancy, should, in contrast, lead to relatively smaller upward revisions, if at all. Formally:

P4: *Performance satisficing*: For extrinsically motivated goals, negative discrepancies lead to significant downward revisions, whereas positive discrepancies lead to relatively small upward revisions.

DERIVING A GOAL-DISCREPANCY RESPONSE FUNCTION

Having identified four principles governing goal updating across periods, our next step is to integrate these principles and thereby derive concrete predictions regarding the relationship between goals and discrepancies. We do this, as we have foreshadowed, by allowing discrepancies to influence the goal itself. In other words, we propose that the goal standard, rather than being a constant, is a dynamic function of the discrepancy between the original goal and the actual performance in a given period. Hence, the objective of this section is to derive a goal-discrepancy response function that predicts, for a given goal and discrepancy, what the updated goal will be. We present the response function graphically as well as mathematically.

Consider a plot of goals and discrepancies on a graph featuring a horizontal discrepancy axis, a vertical goal axis, an upper bound, and a lower bound (see fig. 2). The upper bound stands for the maximum achievement the person can attain given their abilities. Any goal above that bound is essentially out of reach and will eventually be disengaged from. The lower bound stands for the lowest level of attainment that the person can accept. Any goal below the lower bound is not worth pursuing and will be abandoned. In the base case, when there is no discrepancy, there is no reason for the goal to be updated. Hence, the response function must pass through the origin (i.e., the intersection of the two axes), which therefore represents "0" (i.e., no discrepancy) for the discrepancy axis and "original goal" for the goal axis.

Now consider each principle in turn. *Monotonicity* (proposition 1) avers that the magnitude of the goal revision is monotonically related to the magnitude of the goal-performance discrepancy. This determines that the response function is monotonically increasing. In combination with the above base case, we can see that the function exists solely in the first and third quadrants.

The next principle, *diminishing sensitivity* (proposition 2), asserts that discrepancies that are larger in magnitude have a relatively smaller marginal impact on goal revision than do discrepancies that are smaller in magnitude. This implies that the response function should be more sensitive to discrepancies that are closer to the origin than those that lie farther away. As a result, the response function should not be linear, but rather concave in the positive part and convex in the negative part. This, together with the above logic, defines the response function as being S-shaped rather than an inverted S-shape (which would violate *monotonicity*).

The final two principles determine the relative shapes of the curves in the first and third quadrants. For intrinsically motivated goals, the principle of *aspiration maximization* (proposition 3) holds. This principle asserts that positive discrepancies lead to significant upward revisions, whereas negative discrepancies lead to relatively small downward revisions. As a consequence, the positive part of the curve should be steeper than the negative part. Conversely, for extrinsically motivated goals, *performance satisficing* (proposition 4), according to which negative discrepancies lead to significant downward revisions whereas positive discrepancies lead to relatively small upward revisions, indicates that the function has a steeper negative than positive curve.

Putting together the four principles, we see that the response function mapping goals and discrepancies is a monotonically increasing S-shaped function, with asymmetries in the positive and negative parts depending on whether the goal is intrinsically or extrinsically motivated. Figure 2 indicates that despite the various moving parts, the response function we have derived leads to a simple yet comprehensive model.

Indeed, the above logic lends itself to a straightforward mathematical representation, which is important because, as we will explicate in the next section, it represents the key input-output modality of our model. Specifically, we propose that the goal-discrepancy response function may be represented by a logistic function of the following form:

$$g(d) = \frac{a}{(1/s) + e^{-d}} - \frac{a}{(1/s) + 1},$$

where d = discrepancy, g = goal, a = ability > 0, s = self-determination > 0, where $s > 1$ for intrinsically motivated goals and $0 < s < 1$ for extrinsically motivated goals.

The variables in this equation have "real" meaning. Here,

FIGURE 2

(A) GOAL-PERFORMANCE DISCREPANCY RESPONSE FUNCTION FOR INTRINSICALLY MOTIVATED GOALS AND (B) GOAL-PERFORMANCE DISCREPANCY RESPONSE FUNCTION FOR EXTRINSICALLY MOTIVATED GOALS

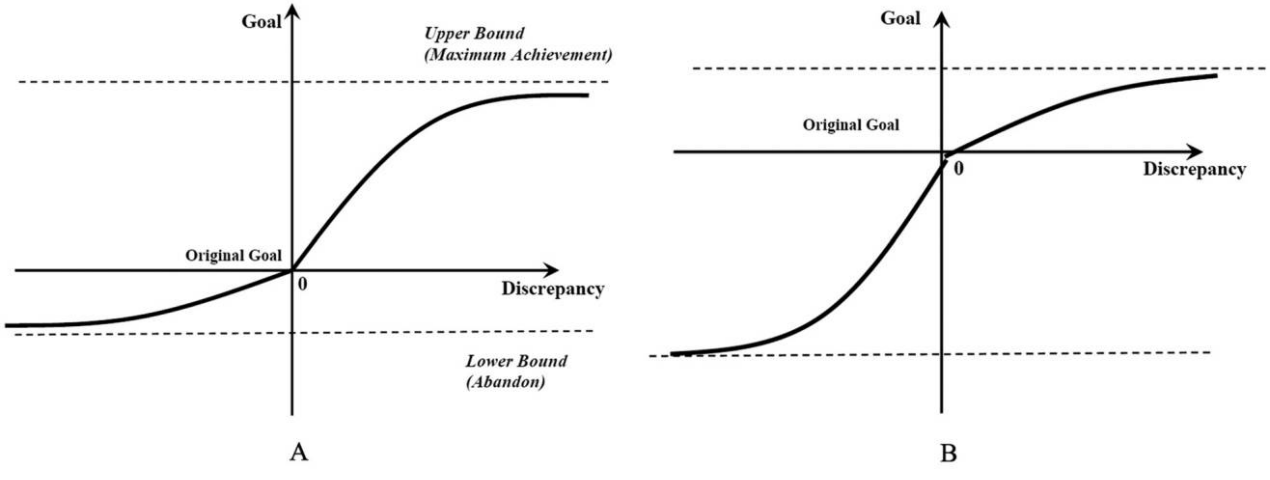
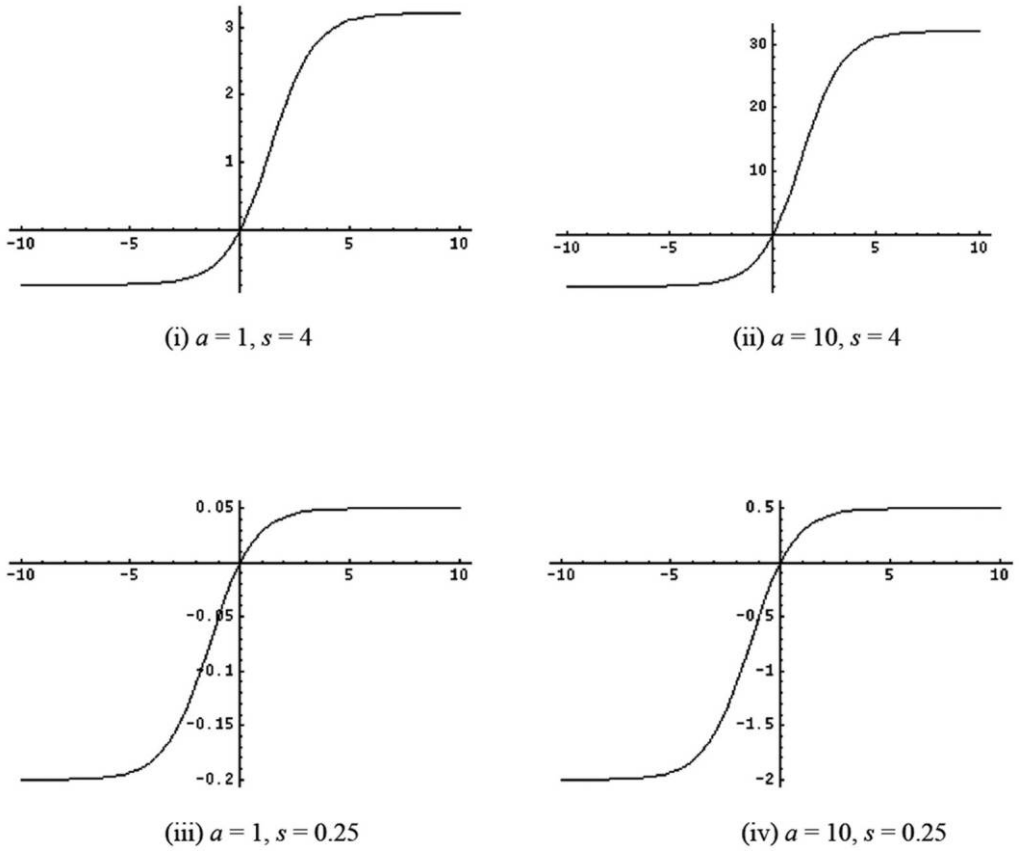


FIGURE 3

NUMERICAL SIMULATIONS FOR THE GOAL-DISCREPANCY RESPONSE FUNCTION



d, the input of the function, is the "discrepancy" between the original goal and the actual performance in a given time period. (Note that in this formulation, d is in specific units [e.g., calories, dollars, minutes] depending on the domain. To make it unit-free and therefore more generalizable, we will introduce a *scale* parameter [i.e., $d* = d/scale$] in the parameter estimation section.) The output, $g(d)$, is the updated "goal" standard generated based on the input d for the next time period. Here $g(0)$ equals the value of the original goal standard when there is zero discrepancy. For simplicity, $g(0)$ can be set to 0 [i.e., $g(0) = 0$] by centering all goals at this original value.

The transformation from the input to the output is characterized by the person-situation specific variables a and s, both of which have critical psychological meanings. In particular, a refers to the "ability" that an individual can use to reach her full potential toward a specific goal. Research on expertise finds that a person's highest level of performance is greatly determined by his or her capability and potential (Chase and Simon 1973; Chi et al. 1982). Mathematically, we see that the values of $g(+\infty)$ and $g(-\infty)$, representing the upper and lower bounds of the goal, are determined by a (see the appendix). It naturally follows that a represents an individual's ability to reach his or her full potential in a specific goal domain. This further implies that larger a, namely, greater potential, leads to higher $g(+\infty)$, or eventual achievement if the potential is fully realized. To illustrate, we conducted some numerical simulations that illustrate the impact of a on the upper/lower bounds (see panels i vs. ii and iii vs. iv in fig. 3).

The variable s refers to "self-determination," that is, "the degree to which the motivation emanates from the self" (Ryan and Deci 2000a, 2000b). It may be visualized on the motivation continuum (Deci and Ryan 1985), as characterizing the ratio between the distance to the right end (i.e., extreme intrinsic orientation) and distance to the left end (i.e., extreme extrinsic orientation). In particular, if self-determination > 1, meaning that the goal is located on the right-hand side on the continuum, then the goal is considered to be more intrinsically motivated. In contrast, if $0 <$ self-determination < 1, then it is located on the left-hand side

of the continuum and the goal is thus more extrinsically motivated.

Recall the principles of *aspiration maximization* (proposition 3) and *performance satisficing* (proposition 4), whereby positive discrepancies lead to more significant upward revision than negative discrepancies if self-determination > 1, and vice versa if 0 < self-determination < 1. Now consider the goal-discrepancy response function. It can mathematically be shown that, given a discrepancy $d(d > 0)$, $|g(d) - g(0)| > |g(-d) - g(0)|$ if $s > 1$ and $|g(d) - g(0)| < |g(-d) - g(0)|$ if $0 < s < 1$ (see the appendix for proof details). These two inequalities represent the expressions for *aspiration maximization* (proposition 3) and *performance satisficing* (proposition 4), which lead to the conclusion that s refers to self-determination. Therefore, reflecting propositions 3 and 4 on the plot of the response function, the positive curve is steeper than the negative curve if $s > 1$, whereas the positive curve is flatter than the negative curve if $0 < s < 1$ (see panels i and iii, and ii and iv, of fig. 3).

Finally, note that $s = 1$ indicates that s is located right on the midpoint between intrinsic and extrinsic motivations. This case corresponds to *integrated regulation*, the most autonomous form of extrinsic motivation (Deci and Ryan 1985; Ryan and Deci 2000a, 2000b). According to self-determination theory, *integrated regulation* shares many qualities with intrinsic motivation, but aims to attain separable outcomes rather than inherent enjoyment. In our investigation, we mainly focus on the majority cases with a clear motivation orientation, although propositions 1 and 2 also apply when $s = 1$.

Having presented the goal-discrepancy response function in the mathematical format, for purposes of completion, we now restate the four principles of goal revision mathematically:

P1: *Monotonicity*:

$$|g(d) - g(0)| > |g(d') - g(0)|,$$

where $d > d' \geq 0$ or $d < d' < 0$.

P2: *Diminishing sensitivity*:

$$|g(d + \Delta) - g(d)| > |g(d' + \Delta) - g(d')|,$$

where $d > d' \geq 0$ or $d < d' < 0$; $\Delta > 0$ is sufficiently small.

P3: *Aspiration maximization*:

$$|g(d) - g(0)| > |g(-d) - g(0)|,$$

where $d \geq 0$.

P4: *Performance satisficing*:

$$|g(d) - g(0)| < |g(-d) - g(0)|,$$

where $d \geq 0$.

THE PROPOSED TOTAL MODEL OF SELF-REGULATION

Goal Calibrator

The final step in the development of our model is to return to the TOTE models and incorporate the above principles of goal revision, as captured by the goal-discrepancy response function, into a complete Test-Operate-Test-Adjust-Loop (TOTAL) model of self-regulation. Again, we treat the CS model (see fig. 1*A*), which is the most evolved TOTE model, as our point of departure. Since the CS model only speaks to a static goal in a single period, in order to extend it to accommodate multiple periods, we introduce an additional element from cybernetic control theory. This new element, which we term a "goal calibrator," is analogous to a controller in cybernetics. A controller is essentially a device that monitors and affects the operational conditions of a given dynamical system (Wiener 1948). For example, the simplest types of controllers (known as proportional controllers) generate desired outcome variables that are proportional to the measured error or discrepancy. Accordingly, our proposed goal calibrator is analogous in function, but more complex in operation: it takes the goal-performance discrepancy as the error input and generates an updated goal as the outcome, one that is not merely proportional, but rather based on the S-shaped response function. In effect, the goal calibrator generates the updated goal standard as a dynamic function of the discrepancy, based on the four principles of goal revision.

Proposed Model

The revised model incorporating the goal calibrator is depicted in figure 1*B*. In our new model, the goal-performance discrepancy serves not only as the input to the system, as suggested by the original CS model, but also as the input to the goal calibrator, generating the updated goal for further monitoring.

The revised cybernetic model of self-regulation works in a TOTAL fashion, as follows. The system initially *tests* the performance against a goal standard at the comparator. If the comparison reveals a discrepancy, an *operate* takes place to generate the performance outcome for the next episode. After that, a *test* recurs to see whether there exists any discrepancy between the new performance and the original goal. Up to this stage, the work flow remains the same as the original TOTE model. If the second test detects any discrepancy between the new performance and the original goal, the goal calibrator takes this discrepancy as the input and *adjusts* the goal standard by operating the S-shaped response function. If the goal is intrinsically motivated, the calibrator employs the principles of *monotonicity*, *diminishing sensitivity*, and *aspiration maximization*. In contrast, if the goal is extrinsically motivated, the calibrator implements *monotonicity*, *diminishing sensitivity*, and *performance satisficing*. The outcome of the goal calibrator is thus the updated goal that serves as an input for the system, and, to-

gether with the performance in the subsequent period, generates the next goal-performance discrepancy, thereby *looping* every period during the course of goal pursuit, and spurring the dynamics of goal revision.

Summary

To summarize, the present research investigates the dynamics of goal revision. In our theorizing, we first present four principles of goal revision (*monotonicity*, *diminishing sensitivity*, *aspiration maximization*, and *performance satisficing*) based on an integrative review of the existing literature. Consistent with the four principles, we propose that the goal is a dynamic function rather than a constant value, specifically, an S-shaped function of the goal-performance discrepancy. We further suggest a mathematical expression for the response function, featuring psychologically meaningful variables. We then fit the response function into a classic cybernetic model of self-regulation by incorporating an additional element, a goal calibrator. This calibrator is directed by the S-shaped response function, based on which it generates updated goals for further monitoring. The revised cybernetic model operates in a Test-Operate-Test-Adjust-Loop (TOTAL) fashion, capturing the dynamics of goal revision. Taken together, the four principles of goal revision, the S-shaped response function, and the cybernetic TOTAL model present a comprehensive picture of self-regulation over multiple periods.

In what follows, we present an initial test of these principles in a series of four laboratory experiments, and we further test the fitness of the response function by using the experimental data to estimate its parameters. We conclude with limitations and future research directions that the model generates.

EMPIRICAL VALIDATION

Pilot Study

The goal of the pilot study was to identify a set of tasks that differed in intrinsic versus extrinsic motivation. Twenty undergraduate students were recruited on campus at the University of British Columbia to voluntarily complete a short questionnaire, in which they reported their intrinsic motivation toward three tasks—saving money, solving anagrams, and working out on the treadmill. The measures, including "I believe this activity could be of some value to me" and "I think this is an important activity" (on 7-point scales: 1 = not at all true, 7 = very true; all α's > .85), were adapted from the Intrinsic Motivation Inventory (Deci et al. 1994; Plant and Ryan 1985; Ryan 1982; Ryan, Connell, and Plant 1990; Ryan, Koestner, and Deci 1991; Ryan, Mims, and Koestner 1983). The results demonstrated that saving money and working out were more important and more intrinsically motivating, compared to solving word puzzles (M_{savings} vs. $M_{\text{puzzles}} = 5.87$ vs. 3.08; $t(19) = 6.89$, $p < .001$; M_{workout} vs. $M_{\text{puzzles}} = 5.30$ vs. 3.08; $t(19) = 5.70$, $p < .001$). Also, there was no difference between saving money and working out; both were high in intrinsic motivation ($t(19) = 1.41$, $p > .17$). Therefore, in the following experiments, we used saving money and working out as intrinsically motivated goals, and solving anagrams as an extrinsically motivated goal.

Experiment 1: Monotonicity

To test *monotonicity* (proposition 1), we used a 2 (discrepancy valence: positive vs. negative) × 2 (discrepancy magnitude: small vs. large) between-subjects design, with working out as the target goal. One hundred undergraduate students at the University of Iowa participated for course credit. Participants were asked to imagine they had a goal of burning 200 calories on the treadmill. The goal-performance discrepancy was manipulated by giving hypothetical outcomes such as "after 30 minutes, you find that you have actually burnt 10 [vs. 110] calories more [vs. less]." Based on the manipulated feedback, participants were asked to write down the number of calories they would like to burn the next day.

A 2 × 2 ANOVA on the size of the goal revision demonstrated, as predicted, that there was a significant main effect of discrepancy magnitude (M_{10} vs. $M_{110} = 23.71$ vs. 98.94; $F(1, 98) = 70.40$, $p < .001$). Follow-up contrasts showed that within both the negative and the positive discrepancy condition, large discrepancies led to greater goal revision than did small discrepancies (M_{+10} vs. $M_{+110} = 28.00$ vs. 125.76; $F(1, 48) = 82.33$, $p < .001$; M_{-10} vs. $M_{-110} = 19.74$ vs. 69.78; $F(1, 48) = 16.86$, $p < .001$), thereby demonstrating *monotonicity*. No other main or interactive effect was significant.

Experiment 2: Aspiration Maximization

The aim of this study was to test *aspiration maximization* (proposition 3) for intrinsically motivated goals. Undergraduate students ($N = 121$) at the University of Iowa participated for course credit. In the context of saving money, we used a 2 (discrepancy valence: positive vs. negative) × 5 (month replicate) mixed design. Participants were asked to write down their savings targets in U.S. dollars for the coming month (March). Discrepancy was manipulated by telling participants to "suppose at the end of the month, you actually have saved [15%] [more] than your goal." The performance outcomes were always either positive or negative based on feedback condition, and the value of the outcome was a random integer between 15% and 19%. Based on the feedback, participants were asked to set up their financial goal for the next month, and the next feedback was presented after that. These procedures were repeated for five iterations.

A 2 (discrepancy valence) × 5 (month) mixed ANOVA revealed, as expected, a significant interaction ($F(4, 116) = 2.55$, $p < .05$) between the discrepancy valence and the monthly target. The pattern was consistent with *aspiration maximization*. That is, positive discrepancies resulted in continuous upward goal revision such that savings targets for each month were higher than in the previous month (M_{Mar} vs. M_{Apr} vs. M_{May} vs. M_{Jun} vs. $M_{\text{Jul}} = 218$ vs. 250 vs. 288

vs. 331 vs. 373; contrast for linear trend $p < .005$). In contrast, negative discrepancies led to much less revision (M_{Mar} vs. M_{Apr} vs. M_{May} vs. M_{Jun} vs. M_{Jul} = 190 vs. 196 vs. 209 vs. 212 vs. 214; contrast for linear trend $p > .09$). These values map onto our proposed S-shaped function for intrinsically motivated goals: steep in the positive and flat in the negative part (see fig. 4).

Experiment 3: Performance Satisficing

The aim of this study was to test *performance satisficing* (proposition 4). Based on the pilot study, we used solving anagrams as an extrinsically motivated goal (also adapted from Tolli and Schmidt 2008). Forty-two undergraduate students at the University of Iowa participated for course credit. Similar to experiment 2, we used a 2 (discrepancy valence: positive vs. negative) × 3 (iterations) mixed design. Participants were asked to form as many words as they could from given sets of scrambled letters. For example, the letters "O L S P O" could form the words "pool," "so," "slop," and "loops." After receiving their instructions, participants were asked to freely set up a goal for the first anagram (i.e., "to find __% of the possible solutions"). The next screen presented the anagram and the space to type in answers. After submitting their answers for this anagram, participants were presented with manipulated feedback such as "Congratulations! You solved 10% more than your goal" in the positive condition, and "Sorry! You solved 10% less than your goal" in the negative condition. Based on the feedback, participants set up their goal for the second anagram. This procedure was repeated for three anagrams.

A 2 × 3 mixed ANOVA revealed a significant interaction consistent with our prediction ($F(2, 39) = 10.317, p < .001$). Specifically, those with positive feedback tended to stick to the original goal (M_1 vs. M_2 vs. M_3 = 63.9 vs. 63.6 vs. 66.9, contrast for linear trend $p > .3$), while those with negative feedback significantly lowered their goals continuously (M_1 vs. M_2 vs. M_3 = 66.5 vs. 52.1 vs. 48.6, contrast for linear trend $p < .005$). These results recover an S-shaped response function, which, in contrast to experiment 2, features a flat positive curve and a steep negative curve (see fig. 5).

Experiment 4: Diminishing Sensitivity

Experiment 4 aimed primarily to test *diminishing sensitivity* (proposition 2) and also to provide further support for *aspiration maximization* and *monotonicity*. We used a 2 (discrepancy valence: positive vs. negative) × 2 (discrepancy magnitude: small vs. large) mixed design with the first factor between subjects and the second factor within subjects. Eighty-nine undergraduate students at the University of British Columbia participated for course credit. As before, participants were instructed to imagine that they had established an initial goal: 100 calories in the positive discrepancy condition, and 500 calories in the negative discrepancy condition. Then each participant was presented with four randomly ordered outcomes as manipulated feedback: 10 calories, 20 calories, 410 calories, 420 calories—all either positive or negative according to the condition. In each case, they were asked to set a goal for the next day, given the current feedback.

The dependent variable was the difference in goal revision between the small and the large discrepancy. A 2 × 2 mixed ANOVA found no significant interaction between the valence and the magnitude of the discrepancy ($F(1, 87) = .66$, $p > .40$, NS) but there was, as predicted, a main effect of discrepancy magnitude ($F(1, 87) = 8.59$, $p < .01$). Follow-up contrasts established that the marginal impact of small discrepancies on goal revision was significantly greater than that of large discrepancies, for positive ($M_{|g(+20)-g(+10)|}$ vs.

FIGURE 4

RESPONSE FUNCTION FOR EXPERIMENT 2: ASPIRATION MAXIMIZATION

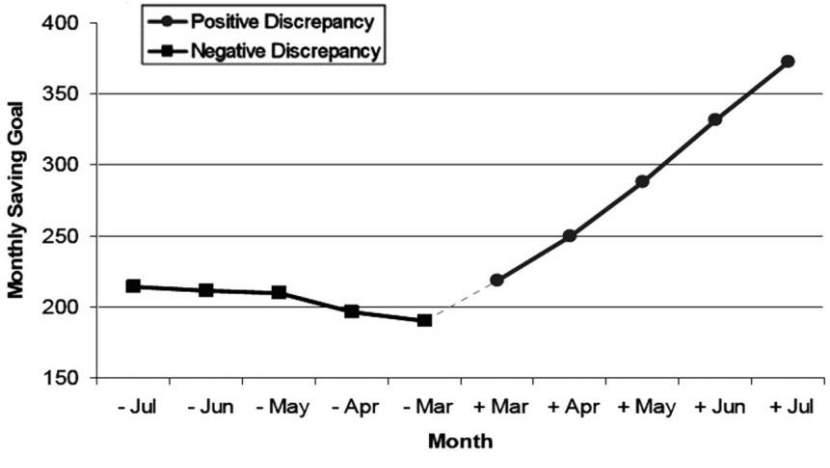
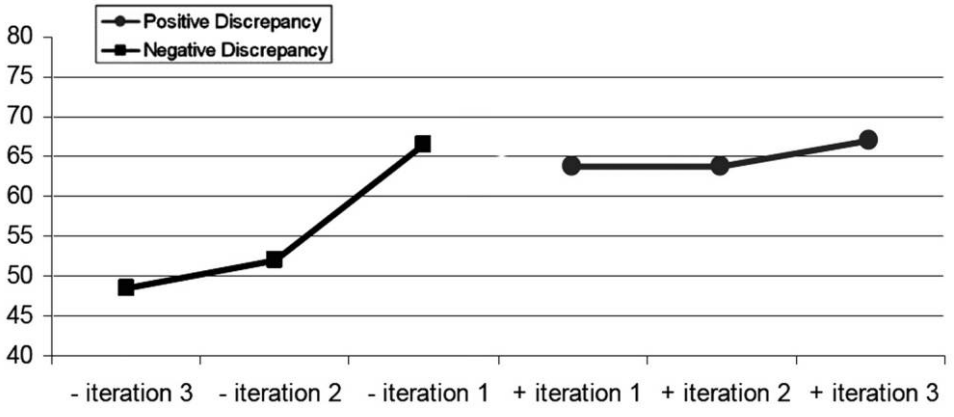


FIGURE 5

EXPERIMENT 3 RESULTS: PERFORMANCE SATISFICING

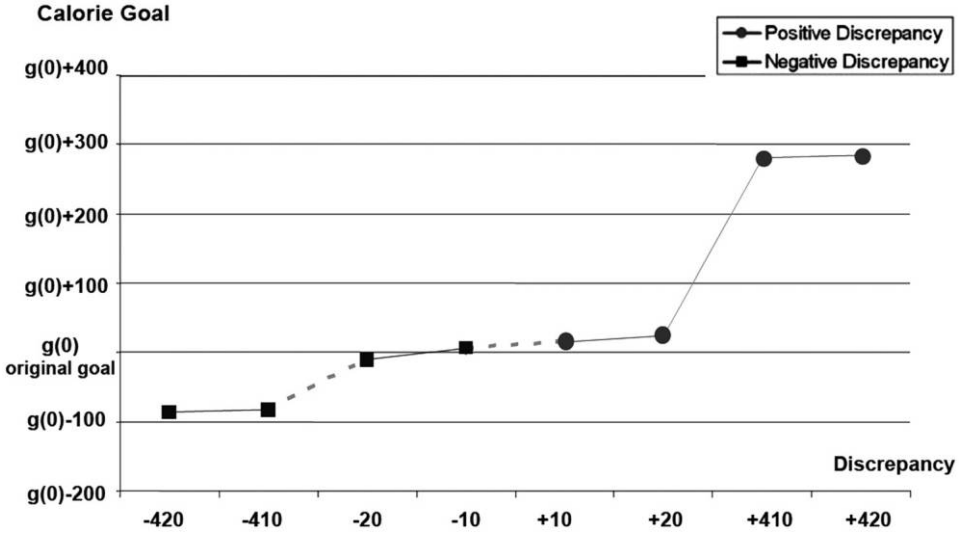


$M_{|g(+420)-g(+410)|} = 9.89$ vs. 3.30; $F(1, 87) = 8.47$, $p < .01$) as well as negative discrepancies ($M_{|g(-20)-g(-10)|}$ vs. $M_{|g(-420)-g(-410)|} = 15.78$ vs. 4.11; $F(1, 87) = 4.12$, $p < .05$). These results are consistent with *diminishing sensitivity*, showing that the marginal impact on the goal revision diminished from small to large discrepancies.

Additional analyses indicated that the other principles for intrinsically motivated goals also held in the data. Specifically, large discrepancies led to large goal revision ($M_{|g(+10)-100|}$ vs. $M_{|g(+410)-100|} = 15.57$ vs. 285.68; $F(1, 87) = 96.24$, $p < .001$; $M_{|g(-10)-500|}$ vs. $M_{|g(-410)-500|} = 8.67$ vs. 189.44; $F(1, 87) = 57.00$, $p < .001$), thereby demonstrating *monotonicity*. Moreover, positive discrepancies caused upward goal revision ($M_{g(+10)}$ vs. $M_{g(+20)}$ vs. $M_{g(+410)}$ vs. $M_{g(+420)} = 114.66$ vs. 124.55 vs. 380.68 vs. 383.98), whereas negative discrepancies led to the relative maintenance of the initial goal ($M_{g(-10)}$ vs. $M_{g(-20)}$ vs. $M_{g(-410)}$ vs. $M_{g(-420)} = 505.56$ vs. 489.78 vs. 417.89 vs. 413.78), thereby demonstrating *aspiration maximization*. As before, the pat-

FIGURE 6

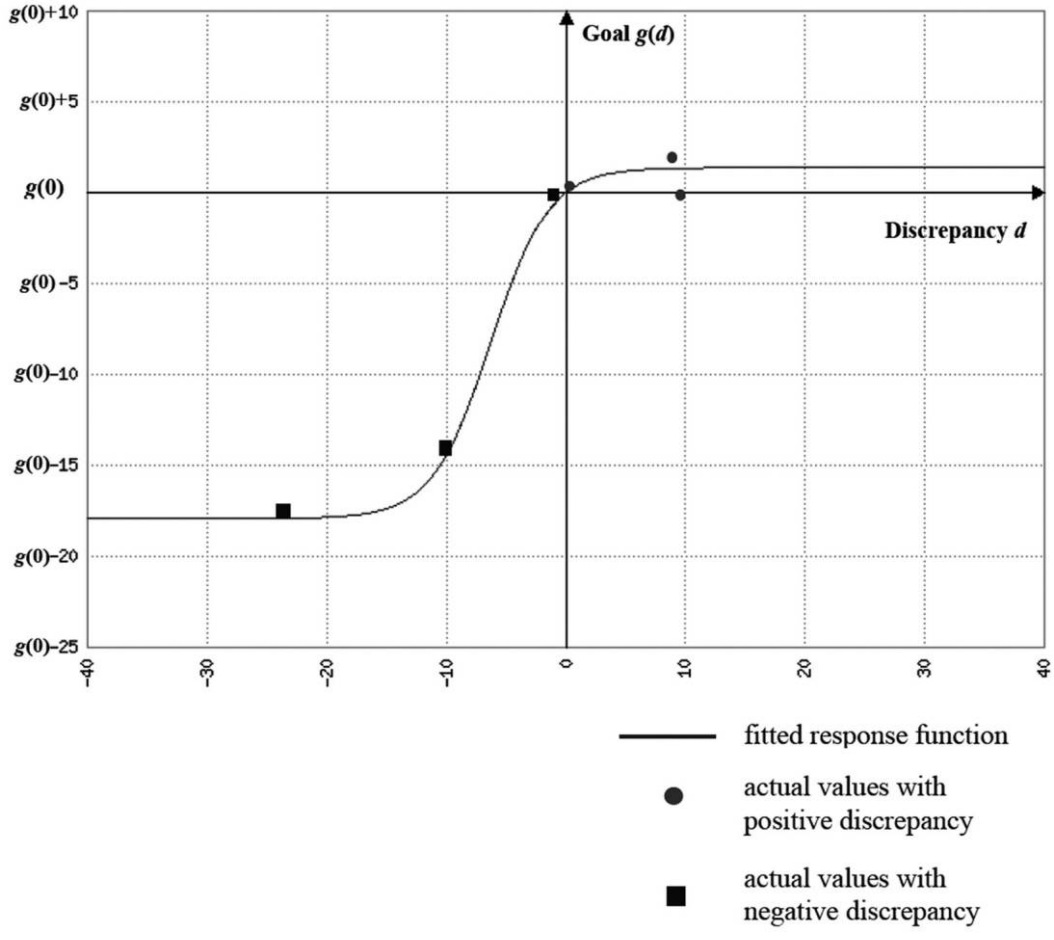
EXPERIMENT 4 RESULTS: DIMINISHING SENSITIVITY



NOTE.—Original goal [i.e., $g(0)$] = 100 calories in the positive discrepancy condition and 500 calories in the negative discrepancy condition.

FIGURE 7

FITTED GOAL-DISCREPANCY RESPONSE FUNCTION AND ACTUAL GOAL VALUES FOR EXPERIMENT 3



tern mapped onto the S-shaped function with a steep positive curve and a flat negative curve (see fig. 6).

Parameter Estimation

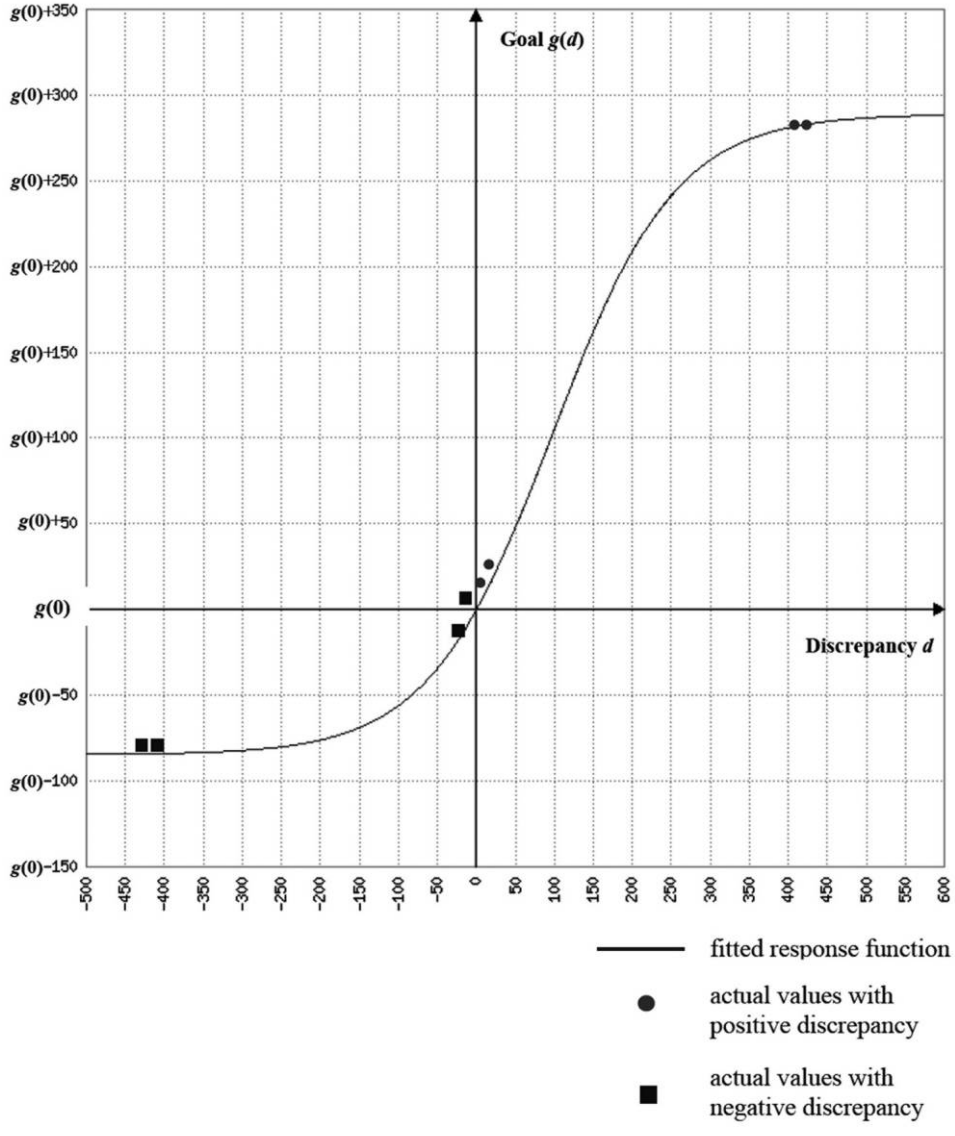
Having empirically tested the four principles in a series of four lab experiments, we next use the experimental data to estimate the parameters of the response function. Due to the nonlinear nature of the response function, we adopt the nonlinear least squares approach (NLS; Hartley and Booker 1965). NLS has been widely used in nonlinear regression (Bates and Watts 1988), and a common application in marketing has been the estimation of the Bass diffusion model (Bass, Krishnan, and Jain 1994; Srinivasan and Mason 1986). In our case, we conduct NLS to estimate the parameters in the goal-discrepancy response function $g(d)$, by minimizing $\Sigma[g_i - g(d_i)]^2$, where g_i is the ith observation and $g(d_i)$ is the ith prediction from the discrepancy d_i.

We use the data from experiments 3 and 4 to estimate the parameters for an extrinsically, and an intrinsically, motivated goal, respectively. (The data in experiments 1 and 2 were obtained from limited trials and random feedback, respectively, which are not appropriate for parameter estimation.) As foreshadowed in the model development section, estimation of this model benefits from a *scale* parameter that makes the input discrepancy d independent of its unit (e.g., hours or minutes, grams or kilograms). This lends stability and generalizability to the response function; without it, the shape of the response would vary dramatically depending on the units used for the same input values. Hence, we estimate the scaled discrepancy $d^* = d/scale$, where the scale parameter is also to be estimated. Therefore, we conduct NLS to estimate the parameters a (ability), s (self-determination), and *scale*, by minimizing the sum of squared residuals $\Sigma[g_i - g(d_i^*)]^2$. The estimation results for experiments 3 and 4 are summarized in table 1.

As is evident in table 1, the experimental data fit very well with the response function ($R^2 = .97$ in experiment 3

FIGURE 8

FITTED GOAL-DISCREPANCY RESPONSE FUNCTION AND ACTUAL GOAL VALUES FOR EXPERIMENT 4



and .99 in experiment 4). Importantly, the estimates of s are consistent with our formulation of self-determination. That is, $s = .08$ in experiment 3 corresponds to the extrinsic motivation associated with the experimental anagrams task ($0 < s < 1$), whereas $s = 3.42$ in experiment 4 highlights the intrinsic nature of the calorie-burning domain ($s > 1$). Moreover, the estimates of a serve as measures of ability in the relevant domains and indicate the full potential that may be reached. The plots of the fitted response function with the experimental data (figs. 7 and 8) demonstrate strong support for the proposed model.

GENERAL DISCUSSION

This research investigates the dynamics of goal revision and proposes a comprehensive conceptual model of how people update their goals across periods in response to goal-performance discrepancies. We first present four principles of goal revision based on an integrative literature review, suggesting that goal-performance discrepancy leads to goal updating according to the universal principles of *monotonicity* and *diminishing sensitivity*, as well as *aspiration maximization* uniquely for intrinsically motivated goals, and *per-*

TABLE 1

PARAMETER ESTIMATES FOR EXPERIMENTS 3 AND 4

	R^2	*a* (Ability)	*s* (Self-determination)	Scale
Experiment 3 (extrinsic goal)	.97	251.53	.08	2.46
Experiment 4 (intrinsic goal)	.99	109.37	3.42	79.14

formance satisficing specifically for extrinsically motivated goals. We believe this is the first piece of work to identify these principles and bring them together. Consistent with the four principles, we propose that the goal is a dynamic function rather than a constant value, specifically, an S-shaped function of the goal-performance discrepancy. Based on the four principles and their features, we further develop a mathematical expression for the response function in line with the psychological meanings of its constituent variables. We then fit the response function into a classic cybernetic model of self-regulation by incorporating an additional element, a goal calibrator. This calibrator is directed by the goal-discrepancy response function, generating updated goals for further monitoring. The revised cybernetic model operates in a Test-Operate-Test-Adjust-Loop (TOTAL) fashion, capturing the dynamics of goal revision. Four experiments provide initial support for the postulates of this model. Overall, the conceptual framework, consisting of the four principles of goal revision, the S-shaped response function with its mathematical expression, and the cybernetic TOTAL model, presents a comprehensive view of the dynamics of self-regulation over multiple periods.

Theoretical Contributions

This research develops a comprehensive model of goal setting and revision across multiple periods. Most previous research on goal-directed behaviors has focused on a static snapshot in time, looking at behaviors directed toward a fixed goal (Austin and Vancouver 1996; Carver and Scheier 1981; Locke and Latham 1990). Yet, most goal-directed behaviors are carried out over multiple periods and are dynamic in nature. Our TOTAL model thus contributes to our knowledge because not only does it qualitatively summarize the principles driving goal revision, but also, as importantly, it quantitatively characterizes the goal updating process using the goal-discrepancy response function. It represents a significant and nontrivial extension to the existing literature—synthesizing and extending, as it does, the CS platform with the four principles, the response function, and the goal calibrator. We believe this is a complete model of goal-directed behavior that encapsulates pursuit, achievement, failure, and abandonment. This research advances our understanding of people's goal-directed behaviors by being the first to present a comprehensive framework of self-regulation over multiple periods.

We believe that cybernetic models in general, and the CS model in particular, are ideal platforms to study the dynamics of goal revision. Cybernetic frameworks have been suggested as parsimonious heuristic devices (Campion and Lord 1982; Lord and Hanges 1987) capable of integrating a multiplicity of theoretical perspectives while retaining a fundamental simplicity (Klein 1989), and cybernetic control theory explicitly recognizes an organism's changing actions according to its interactions with the environment over time (Wiener 1948). Given the above, it is interesting to note that no existing model explicitly addresses the dynamics of goal revision over multiple periods. Carver and Scheier touch upon this issue by suggesting that the goal "changes character as the person traverses the path of activity" and that feedback processes "apply perfectly well to moving targets" (Beer 1995; Carver 2004). We agree that when the moving reference is considered as fixed at a certain value, the original CS model does indeed work very well. However, the framework as it stands only accommodates such static standards, and not any "moving targets." The mechanisms regarding when and how the standard gets updated remain unclear. Carver and Scheier suggest that their model may be extended to capture the adjustment of the reference value (Carver and Scheier, 1998, 26, 151; 2000), using a secondary, weaker, feedback path, which adjusts the reference value based on the output. However, again, they do not discuss how the reference value changes. Instead, they note that the secondary path "has a more gradual effect than the other path" and direct it to the affective consequences. To date, we are unaware of any empirical evidence that supports this proposition.

Limitations and Future Directions

This research is extensive in its scope, and much remains to be done. In what follows, we list some of the more pertinent limitations and discuss possible areas for future investigation.

Discrepancy Feedback. For clarity and simplicity, our experiments always maintained feedback within a condition to be either strictly positive or negative. It would be interesting to study the effects of alternating or even randomized feedback. As a further step toward ecological validity, one might examine the effects of feedback that is delayed. A related question involves the credibility of the feedback and the extent to which it is subjectively interpreted. It is possible that people underweight or even overlook negative discrepancies as a motivational mechanism, to prevent themselves from adjusting their goals downward. Alternately, it is possible that they neglect positive discrepancy feedback to prevent the possibility of coasting. Moreover, the idea that there may be different interpretations of the same objective feedback cue lends itself to the entirely reasonable proposition that there may exist individual differences in attending to, interpreting, and processing the feedback information. An investigation of these processes could shed light on, for instance, the mechanisms driving optimism.

Another related question concerns responses to small dis-

crepancies. Our model draws a strict conceptual distinction between a discrepancy that is marginally positive and one that is marginally negative. However, there are both perceptual and motivational mechanisms to suggest that the origin may not be as strictly defined—there may be a fuzzy "zone of acceptance" around which there is no updating. This would imply that the response function, rather than being kinked at the origin, has instead a small flat region lying along the x-axis.

Empirics. The experiments we report represent a first step in testing the predictions derived from our model. These predictions should be tested in other settings and with field data. Moreover, in our test, the parameter estimates were constrained at a group level. Future research could identify and quantify the determinants of a and s at the individual level. It is worth noting here that we have defined a as a person's potential, which is a constant determined exogenously. However, it is possible to conceive of ability as a point-in-time variable dependent on factors such as practice and fatigue. This different conceptualization would naturally lead to a different mathematical representation, but we are unsure about its parsimony or indeed usefulness.

Extensions. Our model may be extended and applied in many ways. For instance, future research could extend it to the study of multiple goals, which may be represented as several interrelated loops, such that attention and resources directed toward one loop reduce the amount of resources invested in the others. Such a model may be similarly extended for subgoals, hierarchical goals, and so on. Further, the dynamics of goal revision might be different given different types of goals, such as promotion versus prevention (Higgins 1997). Individual differences such as optimism (Zhang et al. 2007), self-awareness (Kruger and Dunning 1999), risk preference (Seo, Goldfarb, and Barrett 2010), or lay theories (Mukhopadhyay and Johar 2005) may lead to differences in responses to success or failure. Indeed, our model can be used to back out individual factors such as ability and self-determination, by observing a person's goal-setting patterns. That is, our model can be used to actually infer whether a goal is intrinsic or extrinsic, by observing a person's goal-setting patterns and then either making a subjective judgment or calculating s. It would also be interesting to study the affective consequences of goal revision. The CS model regards positive and negative affect as epiphenomenal, being driven by progress that is either satisfactory or not (Mukhopadhyay and Johar 2007). However, what might affective consequences be for goals that are ongoing? Optimism may lead to lighthearted perseverance; however, Kuhl and Helle (1986) implicated attempts to reach an unreachable goal as a major factor in causing depression. It is also possible that reneging on an unreachable goal could cause positive emotions, such as relief, whereas continuous upward revision of a desired goal contributes to stress and tension. All of these indicate that the study of the dynamics of goal revision is a very rich and potentially rewarding area for future investigation.

Conclusion

In conclusion, the cybernetic TOTAL model, consisting of the four principles of goal revision and the S-shaped response function with its mathematical expression, advances prior knowledge by presenting a comprehensive view of the dynamics of self-regulation over multiple periods. In this research, we have attempted to bridge the multiple disciplines of consumer behavior, psychology, engineering, and mathematical modeling. As an interdisciplinary science, consumer behavior is well suited to facilitate an integrative approach to the advancement of knowledge, and we believe that our research is one discrepancy-reducing step in that direction.

APPENDIX

Demonstrate that the proposed mathematical expression for the goal-discrepancy response function $g(d)$ satisfies the requirements for the dynamics of goal revision, where

$$g(d) = \frac{a}{(1/s) + e^{-d}} - \frac{a}{(1/s) + 1},$$

where $a > 0$, $s > 0$, in which $s > 1$ for intrinsically motivated goals, and $0 < s < 1$ for extrinsically motivated goals.

Proof. We need to demonstrate that $g(d)$ passes through the origin (0, 0), and that $g(d)$ satisfies the four principles (propositions 1–4). Next, we demonstrate each feature in turn.

i) $g(d)$ passes through (0, 0), namely, $g(0) = 0$.

$$g(0) = \frac{a}{(1/s)e^{0}} - \frac{a}{(1/s) + 1}$$

$$= \frac{a}{(1/s) + 1} - \frac{a}{(1/s) + 1} = 0$$

ii) *Monotonicity*: $|g(d) - g(0)| > |g(d') - g(0)|$, where $d > d' \geq 0$ or $d < d' < 0$.

Since $g(0) = 0$, we only have to prove that $|g(d)| > |g(d')|$.

If $d > d' \geq 0$, we have

$$g(d) = \frac{a(1 - e^{-d})}{[(1/s) + e^{-d}][(1/s) + 1]} \geq 0,$$

$$g(d') = \frac{a(1 - e^{-d'})}{[(1/s) + e^{-d'}][(1/s) + 1]} \geq 0.$$

Then,

$$|g(d)| - |g(d')| = g(d) - g(d')$$

$$= \frac{a(e^{-d'} - e^{-d})}{[(1/s) + e^{-d'}][(1/s) + e^{-d}]} > 0.$$

If $d < d' < 0$, we have

$$g(d) = \frac{a(1 - e^{-d})}{[(1/s) + e^{-d}][(1/s) + 1]} < 0,$$

$$g(d') = \frac{a(1 - e^{-d'})}{[(1/s) + e^{-d'}][(1/s) + 1]} < 0.$$

Then,

$$|g(d)| - |g(d')| = g(d') - g(d)$$

$$= \frac{a(e^{-d} - e^{-d'})}{[(1/s) + e^{-d'}][(1/s) + e^{-d}]} > 0.$$

iii) *Diminishing sensitivity*: $|g(d+\Delta) - g(d)| > |g(d' + \Delta) - g(d')|$, where $d > d' \geq 0$ or $d < d' < 0$; $\Delta > 0$ is sufficiently small.

To demonstrate *diminishing sensitivity*, we can alternatively demonstrate that $g(d)$ has an S-shape and the upper/lower bounds. First, $g(d)$ is a logistic function, which has a typical S-shape. Second, $g(+\infty) = a \cdot s^2/(s + 1)$, which is the upper bound; $g(-\infty) = -a \cdot s/(s + 1)$, which is the lower bound.

iv) *Aspiration maximization*: $|g(d) - g(0)| > |g(-d) - g(0)|$, where $d \geq 0$, $s > 1$.

$$|g(d) - g(0)| - |g(-d) - g(0)| = g(d) - [-g(-d)]$$

$$= \frac{as^2(s - 1)(e^d + e^{-d} - 2)}{(s + 1)(1 + se^{-d})(1 + se^{d})} > 0,$$

since $s > 1$ and $e^d + e^{-d} - 2 > 0$ for all $d > 0$.

v) *Performance satisficing*: $|g(d) - g(0)| < |g(-d) - g(0)|$, where $d \geq 0$, $0 < s < 1$.

$$|g(d) - g(0)| - |g(-d) - g(0)| = g(d) - [-g(-d)]$$

$$= \frac{as^2(s - 1)(e^d + e^{-d} - 2)}{(s + 1)(1 + se^{-d})(1 + se^{d})} < 0,$$

since $0 < s < 1$ and $e^d + e^{-d} - 2 > 0$ for all $d > 0$.

REFERENCES

Atkinson, John (1958), "Towards Experimental Analysis of Human Motivation in Terms of Motives, Expectancies and Incentives," in *Motives in Fantasy, Action and Society*, ed. John Atkinson, Princeton, NJ: Van Nostrand, 288–305.

Austin, James T. and Jeffrey B. Vancouver (1996), "Goal Constructs in Psychology: Structure, Process, and Content," *Psychological Bulletin*, 120 (3), 338–75.

Bagozzi, Richard P. and Utpal M. Dholakia (1999), "Goal Setting and Goal Striving in Consumer Behavior," *Journal of Marketing*, 63 (October), 19–32.

Bandura, Albert and Dale H. Schunk (1981), "Cultivating Competence, Self-Efficacy and Intrinsic Interest through Proximal Self-Motivation," *Journal of Personality and Social Psychology*, 41 (3), 586–98.

Bass, Frank M., Trichy V. Krishnan, and Dipak C. Jain (1994), "Why the Bass Model Fits without Decision Variables," *Marketing Science*, 13 (Summer), 203–23.

Bates, Douglas M. and Donald G. Watts (1988), *Nonlinear Regression Analysis and Its Applications*, New York: Wiley.

Baumgartner, Hans and Rik Pieters (2008), "Goal-Directed Consumer Behavior," in *Handbook of Consumer Psychology*, ed. Curtis P. Haugtvedt, Paul M. Herr, and Frank Kardes, New York: Psychology Press, 367–92.

Beer, Randall D. (1995), "A Dynamical Systems Perspective on Agent-Environment Interaction," *Artificial Intelligence* 72 (January), 173–215.

Brehm, Jack W. and Elizabeth A. Self (1989), "The Intensity of Motivation," *Annual Review of Psychology*, 40 (February), 109–31.

Brunstein, Joachim C. and Peter M. Gollwitzer (1996), "Effects of Failure on Subsequent Performance: The Importance of Self-Defining Goals," *Journal of Personality and Social Psychology*, 70 (2), 395–407.

Campion, Michael A. and Robert G. Lord (1982), "A Control Systems Conceptualization of the Goal Setting and Changing Process," *Organizational Behavior and Human Performance*, 30 (October), 265–87.

Carver, Charles S. (2004), "Self-Regulation of Action and Affect," in *Handbook of Self-Regulation: Research, Theory and Applications*, ed. Roy F. Baumeister and Kathleen D. Vohs, New York: Guilford, 13–39.

Carver, Charles S. and Michael F. Scheier (1981), *Attention and Self-Regulation: A Control-Theory Approach to Human Behavior*, New York: Springer.

——— (1998), *On the Self-Regulation of Behavior*, New York: Cambridge University Press.

——— (2000), "Scaling Back Goals and Recalibration of the Affect System Are Processes in Normal Adaptive Self-Regulation: Understanding 'Response Shift' Phenomena," *Social Science and Medicine*, 50 (12), 1715–22.

Chase, William G. and Herbert A. Simon (1973), "Perception in Chess," *Cognitive Psychology*, 4 (January), 55–81.

Chi, Michelene T. H., Robert Glasser, and Ernest Rees (1982), "Expertise in Problem Solving," in *Advances in the Psychology of Human Intelligence*, Vol. 1, ed. Robert Jeffrey Sternberg, Hillsdale, NJ: Erlbaum, 7–75.

Deci, Edward L. (1975), *Intrinsic Motivation*, New York: Plenum.

Deci, Edward L., Haleh Eghrari, Brian C. Patrick, and Dean R. Leone (1994), "Facilitating Internalization: The Self-Determination Theory Perspective," *Journal of Personality*, 62 (1), 119–42.

Deci, Edward L. and Richard M. Ryan (1985), *Intrinsic Motivation and Self-Determination in Human Behavior*, New York: Plenum.

——— (2000), "The 'What' and 'Why' of Goal Pursuits: Human Needs and the Self-Determination of Behavior," *Psychological Inquiry*, 11 (4), 227–68.

Donovan, John J. and Kevin J. Williams (2003), "Missing the Mark: Effects of Time and Causal Attributions on Goal Revision in Response to Goal-Performance Discrepancies," *Journal of Applied Psychology*, 88 (3), 379–90.

Emmons, Robert A. and Laura A. King (1988), "Conflict among Personal Strivings: Immediate and Long-Term Implications for Psychological and Physical Well-Being," *Journal of Personality and Social Psychology*, 54 (6), 1040–48.

Fishbach, Ayelet and Ravi Dhar (2005), "Goals as Excuses or Guides: The Liberating Effect of Perceived Goal Progress on

Choice," *Journal of Consumer Research*, 32 (December), 370–77.
Fishbach, Ayelet, Ravi Dhar, and Ying Zhang (2006), "Subgoals as Substitutes or Complements: The Role of Goal Accessibility," *Journal of Personality and Social Psychology*, 91 (August), 232–42.
Fishbach, Ayelet, Ying Zhang, and Minjung Koo (2009), "The Dynamics of Self-Regulation," in *European Review of Social Psychology*, Vol. 20, ed. Wolfgang Stroebe and Miles Hewstone, London: Psychology Press, 315–44.
Geen, Russell G. (1995), *Human Motivation: A Social-Psychological Approach*, Belmont, CA: Brooks/Cole.
Gollwitzer, Peter M. (1999), "Implementation Intentions: Strong Effects of Simple Plans," *American Psychologist*, 54 (7), 493–503.
Hartley, Herman O. and Aaron Booker (1965), "Nonlinear Least Squares Estimation," *Annals of Mathematical Statistics*, 36 (2), 638–50.
Higgins, E. Tory (1997), "Beyond Pleasure and Pain," *American Psychologist*, 52 (12), 1280–1300.
Ilies, Remus and Timothy A. Judge (2005), "Goal Regulation across Time: The Effects of Feedback and Affect," *Journal of Applied Psychology*, 90 (3), 453–67.
Karoly, Paul (1993), "Mechanisms of Self-Regulation: A Systems View," *Annual Review of Psychology*, 44, 23–52.
Kasser, Tim and Richard M. Ryan (1996), "Further Examining the American Dream: Differential Correlates of Intrinsic and Extrinsic Goals," *Personality and Social Psychology Bulletin*, 22 (3), 280–87.
Kivetz, Ran, Oleg Urminsky, and Yuhuang Zheng (2006), "The Goal-Gradient Hypothesis Resurrected: Purchase Acceleration, Illusionary Goal Progress, and Customer Retention," *Journal of Marketing Research*, 43 (1), 39–58.
Klein, Howard J. (1989), "An Integrated Control Theory Model of Work Motivation," *Academy of Management Review*, 14 (2), 150–72.
Kruger, Justin and David Dunning (1999), "Unskilled and Unaware of It: How Difficulties in Recognizing One's Own Incompetence Lead to Inflated Self-Assessment," *Journal of Personality and Social Psychology*, 77 (6), 1121–34.
Kuhl, Julius and Petra Helle (1986), "Motivational and Volitional Determinants of Depression: The Degenerated-Intention Hypothesis," *Journal of Abnormal Psychology*, 95 (August), 247–51.
Laran, Juliano (2010a), "Choosing Your Future: Temporal Distance and the Balance between Self-Control and Indulgence," *Journal of Consumer Research*, 36 (April), 1002–15.
——— (2010b), "The Influence of Information Processing Goal Pursuit on Post-decision Affect and Behavioral Intentions," *Journal of Personality and Social Psychology*, 98 (1), 16–28.
Laran, Juliano and Chris A. Janiszewski (2009), "Behavioral Consistency and Inconsistency in the Resolution of Goal Conflict," *Journal of Consumer Research*, 35 (April), 967–84.
——— (2011), "Work or Fun? How Task Construal and Completion Influence Regulatory Behavior," *Journal of Consumer Research*, 37 (April), 967–83.
Latham, Gary P. and Edwin A. Locke (1991), "Self-Regulation through Goal Setting," *Organizational Behavior and Human Decision Processes*, 50 (2), 212–47.
Locke, Edwin A. and Gary P. Latham (1990), *A Theory of Goal Setting and Task Performance*, Englewood Cliffs, NJ: Prentice Hall.
——— (2002), "Building a Practically Useful Theory of Goal Setting and Task Motivation," *American Psychologist*, 57 (9), 705–15.
Lord, Robert G. and Paul J. Hanges (1987), "A Control Systems Model of Organizational Motivation: Theoretical Development and Applied Implications," *Behavioral Science*, 32 (3), 161–78.
Louro, Maria J., Rik Pieters, and Marcel Zeelenberg (2007), "Dynamics of Multiple-Goal Pursuit," *Journal of Personality and Social Psychology*, 93 (2), 174–93.
MacKay, Donald M. (1966), "Cerebral Organization and the Conscious Control of Action," in *Brain and Conscious Experience*, ed. John C. Eccles, Berlin: Springer, 422–45.
Miller, George A., Eugene Galanter, and Karl H. Pribram (1960), *Plans and the Structure of Behavior*, New York: Holt, Rinehart, & Winston.
Mukhopadhyay, Anirban and Gita Venkataramani Johar (2005), "Where There Is a Will, Is There a Way? Effects of Lay Theories of Self-Control on Setting and Keeping Resolutions," *Journal of Consumer Research*, 31 (March), 779–86.
——— (2007), "Tempted or Not? The Effect of Recent Purchase History on Responses to Affective Advertising," *Journal of Consumer Research*, 33 (March), 445–53.
——— (2009), "Indulgence as Self-Reward for Prior Shopping Restraint: A Justification-Based Mechanism," *Journal of Consumer Psychology*, 19 (July), 334–45.
Mukhopadhyay, Anirban, Jaideep Sengupta, and Suresh Ramanathan (2008), "Recalling Past Temptations: An Information-Processing Perspective on the Dynamics of Self-Control," *Journal of Consumer Research*, 35 (December), 586–99.
Novemsky, Nathan and Ravi Dhar (2005), "Goal Fulfillment and Goal Targets in Sequential Choice," *Journal of Consumer Research*, 32 (December), 396–404.
Plant, Robert W. and Richard M. Ryan (1985), "Intrinsic Motivation and the Effects of Self-Consciousness, Self-Awareness, and Ego-Involvement: An Investigation of Internally-Controlling Styles," *Journal of Personality*, 53 (September), 435–49.
Polivy, Janet and C. Peter Herman (2002), "If at First You Don't Succeed: False Hopes of Self-Change," *American Psychologist*, 57 (September), 677–89.
Powers, William T. (1973), *Behavior: The Control of Perception.* Chicago: Aldine.
Riediger, Michaela and Alexandra M. Freund (2004), "Interference and Association among Personal Goals: Differential Associations with Subjective Well-Being and Persistent Goal Pursuit," *Personality and Social Psychology Bulletin*, 30 (12), 1511–23.
Rogers, Timothy B., Nicholas A. Kuiper, and William S. Kirker (1977), "Self-Reference and the Encoding of Personal Information," *Journal of Personality and Social Psychology*, 35 (9), 677–88.
Ryan, Richard M. (1982), "Control and Information in the Intrapersonal Sphere: An Extension of Cognitive Evaluation Theory," *Journal of Personality and Social Psychology*, 43 (3), 450–61.
Ryan, Richard M., James P. Connell, and Robert W. Plant (1990), "Emotions in Non-directed Text Learning," *Learning and Individual Differences*, 2 (1), 1–17.
Ryan, Richard M. and Edward L. Deci (2000a), "Self-Determination Theory and the Facilitation of Intrinsic Motivation, Social Development, and Well-Being," *American Psychologist*, 55 (1), 68–78.
——— (2000b), "Intrinsic and Extrinsic Motivations: Classic Def-

initions and New Directions," *Contemporary Educational Psychology*, 25 (1), 54–67.

Ryan, Richard M., Richard Koestner, and Edward L. Deci (1991), "Ego-Involved Persistence: When Free-Choice Behavior Is Not Intrinsically Motivated," *Motivation and Emotion*, 15 (3), 185–205.

Ryan, Richard M., Valerie Mims, and Richard Koestner (1983), "Relation of Reward Contingency and Interpersonal Context to Intrinsic Motivation: A Review and Test Using Cognitive Evaluation Theory," *Journal of Personality and Social Psychology*, 45 (4), 736–50.

Schmuck, Peter and Kennon M. Sheldon (2001), *Life Goals and Well-Being: Towards a Positive Psychology of Human Striving*, Seattle: Hogrefe & Huber.

Seligman, Martin E. (1975), *Helpless: On Depression, Development, and Death.* San Francisco: Freeman.

Seo, Myeong-Gu, Brent Goldfarb, and Lisa F. Barrett (2010), "Affect and the Framing Effect within Individuals over Time: Risk Taking in a Dynamic Investment Simulation," *Academy of Management Journal*, 53 (2), 411–31.

Simon, Herbert A. (1953), *Models of Man*, New York: Wiley.

——— (1955), "A Behavioral Model of Rational Choice," *Quarterly Journal of Economics*, 69 (1), 99–118.

Slama, Mark E. and Armen Tashchian (1985), "Selected Socioeconomic and Demographic Characteristics Associated with Purchasing Involvement," *Journal of Marketing*, 49 (1), 72–82.

Soman, Dilip and Amar Cheema (2004), "When Goals Are Counterproductive: The Effects of Violation of a Behavioral Goal on Subsequent Performance," *Journal of Consumer Research*, 31 (June), 52–62.

Soman, Dilip and Mengze Shi (2003), "Virtual Progress: The Effect of Path Characteristics on Perceptions of Progress and Choice Behavior," *Management Science*, 49 (September), 1229–50.

Srinivasan, V. and Charlotte H. Mason (1986), "Nonlinear Least Squares Estimation of New Product Diffusion Models," *Marketing Science*, 5 (2), 169–78.

Thaler, Richard H. and Hersh M. Shefrin (1981), "An Economic Theory of Self-Control," *Journal of Political Economy*, 89 (April), 392–406.

Tolli, Adam P. and Aaron M. Schmidt (2008), "The Role of Feedback, Causal Attributions, and Self-Efficacy in Goal Revision," *Journal of Applied Psychology*, 93 (3), 692–701.

Tolman, Edward C. (1932), *Purposive Behavior in Animals and Men*, New York: Century.

Torgerson, Warren S. (1958), *Theory and Methods of Scaling*. New York: Wiley.

Trope, Yaacov and Eva M. Pomerantz (1998), "Resolving Conflicts among Self-Evaluative Motives: Positive Experiences as a Resource for Overcoming Defensiveness," *Motivation and Emotion*, 22 (1), 53–72.

Tsui, Anne S. and Susan J. Ashford (1994), "Adaptive Self-Regulation: A Process View of Managerial Effectiveness," *Journal of Management*, 20 (1), 93–121.

Vohs, Kathleen D., Roy F. Baumeister, Brandon J. Schmeichel, Jean M. Twenge, Noelle M. Nelson, and Dianne M. Tice (2008), "Making Choices Impairs Subsequent Self-Control: A Limited Resource Account of Decision Making, Self-Regulation, and Active Initiative," *Journal of Personality and Social Psychology*, 94 (5), 883–98.

Vohs, Kathleen D., Roy F. Baumeister, and Dianne M. Tice (2008), "Self-Regulation: Goals, Consumption, and Choices," in *Handbook of Consumer Psychology*, ed. Curtis P. Haugtvedt, Paul M. Herr, and Frank R. Kardes, New York: Psychology Press, 349–66.

Wegner, Daniel M. (1994), "Ironic Processes of Mental Control," *Psychological Review*, 101 (1), 34–52.

Wiener, Norbert (1948), *Cybernetics: Control and Communication in the Animal and the Machine,* Cambridge, MA: MIT Press.

Zhang, Ying, Ayelet Fishbach, and Ravi Dhar (2007), "When Thinking Beats Doing: The Role of Optimistic Expectations in Goal-Based Choice," *Journal of Consumer Research*, 34 (July), 567–78.

Zhang, Ying, and Szu-Chi Huang (2010), "How Endowed versus Earned Progress Affects Consumer Goal Commitment and Motivation," *Journal of Consumer Research* 37 (December), 641–54.