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Title: "Control feedback as the motivational force behind habitual behavior"

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Abstract: Motivated behavior is considered to be a product of integration of a behavior's subjective benefits and costs. As such, it is unclear what motivates 'habitual behavior' which occurs, by definition, after the outcome's value has diminished. One possible answer is that habitual behavior continues to be selected due to its 'intrinsic' worth. Such an explanation, however, highlights the need to specify the motivational system for which the behavior has intrinsic worth. Another key question is how does an activity attain such intrinsically rewarding properties. In an attempt to answer both questions, we suggest that habitual behavior is motivated by the influence it brings over the environment — by the control motivation system, including 'control feedback'. Thus, when referring to intrinsic worth we refer to a representation of an activity that has been reinforced due to it being effective in controlling the environment, managing to make something happen. As an answer to when does an activity attain such rewarding properties, we propose that this occurs when the estimated instrumental outcome expectancy of an activity is positive but the *precision* of this expectancy is low. This lack of precision overcomes the chronic dominance of outcome feedback over control feedback in determining action selection by increasing the relative weight of the control feedback. Such a state of affairs will lead to repeated selection of control relevant behavior and entails insensitivity to outcome devaluation, thereby producing a habit.

This chapter explores the relations between control feedback and habitual behavior. Control feedback is the information about the degree of control an organism has over the environment (Eitam et al., 2013). We propose that control feedback will, under certain conditions, induce habitual behavior

The chapter is divided into two major sections. The first selectively reviews existing computational models of action selection and regulation, starting with Cybernetic models (e.g., Carver & Scheier, 1981; Miller et al., 1960; Powers, 1973a) and then models focusing on more elementary actions (e.g., the Comparator model). This section also discusses the role of control feedback as implemented in these frameworks. The second section focuses on habitual versus goal-directed behavior and outlines our conceptual framework for how habitual behavior is acquired and maintained through control feedback. Finally, we discuss some practical implementations that arise from the proposed model, such as eating disorders.

Computational Models of Action Selection and Regulation

Much of our time is invested in the pursuit of goals. Accordingly, the literature on goal pursuit is huge and rife with definitions of goals crossing different levels of analysis (see Higgins & Scholer, 2015; De Houwer & Moors, 2015; Marr, 1982). For instance, a goal is what one is trying to accomplish - the object or aim of an action (Locke et al., 1981); it is a "a cognitive representation of a desired end point that impacts evaluations, emotions and behaviors" (Fishbach & Ferguson, 2007, p.491; Kruglanski, 1996) or a "cognitive representation linking means or actions with desired outcomes” (Mustafic' and Frund, 2012; p.493). Definitions aside, the control of behavior in light of one’s current standing in relation to a goal is required in order to pursue goals successfully. One class of models that has been applied to this process is Cybernetic models.

Cybernetic models of goal directed behavior. According to a cybernetic control model, the overarching objective is to reduce perceived discrepancy between a current state and a desired goal state by relying on feedback processes. The concept of cybernetic control is derived from engineering (Weiner, 1948) and was also inspired by physiology (e.g., homeostasis, Cannon, 1932). Weiner (1948) coined the term 'cybernetic' from the Greek word "steersman" as is proper to the function that this model is designed to achieve (Powers, 1978).

The term "self-regulation", developed in this context by Carver and Scheier (1982; 2011), refers to the "sense of purposive processes, the sense that self-corrective adjustments are taking place as needed to stay on track for the purpose being served" (2011, p.3). The key cybernetic unit is 'the negative feedback loop' (Carver & Scheier, 1982). The 'negative' refers to its function to *reduce* discrepancy between the current state and the desired end-state. The loop is comprised of four functional elements: a reference point, a comparator, and input and output functions. A goal within a negative feedback loop is the reference point one desires or intends to achieve (Carver & Scheier, 1982). The role of the input function is to identify one's current state in respect to that goal. Finally, the comparator continuously compares (monitors) the input function and the reference value. The result of the comparison determines the output function – the behavior that seems appropriate to reduce the gap between the current state and the desired end-state. The output function – through the selected behavior – affects the environment and consequently the perceived input changes until the gap is nullified (Carver & Scheier, 1982, 2011; Miller et al., 1960). See figure 1 to illustration.

[Insert figure 1 here please]

A computational model for motor-action selection. Internal models and comparators also play an important theoretical role in the literature on motor control. Internal models can be distinguished into two types. The first is a 'forward model' that predicts the sensory consequences given a current state and a motor command (Wolpert et al., 1995). This sensory prediction is available due to the simulation of the movement driven by an 'efference copy' of the motor command (Holst & Mittelstaedt, 1950; Sperry, 1950). The second type of model is the 'inverse model', which uses an outcome to infer the motor command that could have produced it (Wolpert et al., 1995).

One of the most influential models of motor control based on the principle of cybernetic control is the Comparator model (Blakemore et al., 1999; Frith, 1992; Frith et al., 2000; Wolpert et al., 1995). The Comparator model itself includes both forward and inverse models and was initially conceived to explain motor execution, learning, and control. The comparator units in the model rely on probabilistic estimation, comparison and inference, and enable quantifying the fit between the desired effects (motor goals), motor commands, and environmental results (Kording & Wolpert, 2006; Wolpert et al., 2003). A first comparator compares the current state and the desired state. A second comparator compares the desired state and the forward model related to the motor command (i.e., the predicted state of the world given execution of the command). A third comparator compares the current state and the predicted state. The model was extended to explain the ‘self-other distinction,’ such as explaining why, when, and how are perceptual sensory effects of self-generated actions versus other-generated actions attenuated (Blakemore et al., 1999; 2000), and how is the estimation of the timing of a self-caused, voluntary action versus involuntary action and its effect shifted one toward the other (Intentional Binding, Haggard et al., 2002).

In particular, the comparator model was expanded to explain the 'sense of agency', the experience one has of controlling one's own actions and the external world, as well as distinguishing when it is one's own action that is responsible for an environmental change (Haggard & Tsakiris, 2009; but see Synofzik et al., 2008). The typical application of the comparator model to the sense of agency includes the second comparator and, especially, the third comparator. An error signal from the first comparator indicates a discrepancy between the current state and the desired state and the need to reselect or modify the motor plan to reduce the error, a process that mirrors a change within the negative feedback unit (Carver &

Scheier, 1982; Miller et al., 1960). The lack of an error signal will result in the smooth selection of the intended behavior until goal completion (Carver & Scheier, 1982; or an 'exit' signal; Miller et al., 1960).

An error signal produced by the third comparator (actual *vs*. own-action predicted state) is directly related to the sense of agency; when an error signal exists, self-causality and control are reduced (Pacherie, 2001; 2007; 2008. But see Synofzik et al., 2008 for limitations). Conversely, when no such error signal is detected – the effect is estimated to be self-generated and this estimation feeds in to downstream processes; for example, evidence from our lab suggests that the motor plan that is responsible for an own-action-effect is rewarded (see further elaboration on this issue in the section below). This is manifested in both faster (Eitam et al., 2013; Karsh & Eitam, 2015a) and more frequent selection of the action (Karsh & Eitam, 2015a).

Although this latter ('third comparator') comparison is absent in the negative feedback loops, which involve the assessment of desired states or outcomes, we propose that control (i.e., self causality) information could have a similar regulatory function, and especially when the information regarding goal or current (goal relevant) state is lacking or imprecise (cf. White, 1959). Regarding mechanism, we suggest adding a similar negative feedback loop to the (existing) third comparator by which the system strives to minimize the discrepancy between the current actual state (striving for agency) and the predicted state. Such an addition would, for example, enable persistence, even when the output of the (outcome-concerned) negative feedback loop is imprecise (noisy) as long as the outcome expectancy is positive. The persistence would be driven by the control-driven negative feedback loop.

***Motivation from control*.** The behaviorist's emphasis on reward and punishment (e.g., Skinner, 1953) is still the basis of many models of motivation in psychology and neuroscience (Steels, 2004). The key assumptions of this framework are as follows: first, the main goal of the organism is to maintain bodily homeostasis (e.g., body temperature); second, this goal is met through the organism's tendency to seek reward and avoid punishment (Beck, 2000; Steels, 2004).

In his book *Beyond Pleasure and Pain*, Higgins (2012) reviews the substantial evidence in the psychological literature that people want (i.e., are motivated by) more than just desired results. Another important source of motivation is 'control' ('managing what happens') and the relation between control and what he termed 'value' (having desired results). Applying this perspective to information processing, Eitam et al. (2013) differentiated between types of information pertaining to different motivations, referring to the information about our standing in relation to a desired outcome as constituting 'outcome feedback,' and the information about the degree of control the organism has over the environment as constituting 'control feedback'. Outcome feedback is the information about progressing toward a goal as discussed above and control feedback is the information that is relevant for decisions of agency. It was assumed that both types of information could motivate action.

Early empirical support for the notion that information about one's control can be motivating appears in Stephens' (1934) largely overlooked paper that documented that, when 'something' happens after a response, it strengthens the corresponding response. And this is even the case for feedback about negative outcomes (see also Thorndike, 1927). Later on, reviewing evidence that animals are seemingly motivated by outcome-neutral events, White (1959) coined the term 'effectance' for the motivation to influence or interact with the environment. An important precursor to our current hypothesis is White's proposal that the hypothesized effectance 'drive' influences behavior even when it does not promise the satisfaction of a current homeostatic need or obtain a tangible reward (i.e., no obtained outcome).[1] Also resonating with the motivating force of control, deCharms (1968) suggested

[1] Another key insight of White's was that the relationship between control and outcome motivation is hierarchical and the latter will control behavior only when the influence of outcome motivation is weakened.

that personal causation is reinforcing; thus when behavior is perceived as stemming from “the person’s choices” it will be valued more than behavior judged to stem from an external force (see also Deci & Ryan, 1985). Similarly, Nuttin (1973) proposed a 'causality pleasure' that is the result of the perception of being the initiator of the action.

Drawing on an analogy with the established motivating effects of outcome feedback (and more generally, of tangible rewards), Eitam et al. (2013) tested whether control feedback also motivates independent of outcomes. As we briefly mentioned above, their research showed that trivial and valence-neutral control feedback (a “flash” following a key press) motivates behavior. In their study, participants were instructed to press one of four keys that corresponded to one of four target stimuli. In one condition (the 'Immediate Effect' condition), immediately after participants pressed a key, the circle changed its color and disappeared. Conversely, for a 'No Effect' condition, the circle merely continued in its downward path, regardless of the key press (participants were assured beforehand that “the game is working properly”). Since, multiple replications showed that participants in the Immediate Effect condition were on average ~30ms faster compared to those in the No effect condition. Recently, Karsh and Eitam (2015a) generalized this finding by using a free choice version of the above paradigm (the EMFC task, see also Karsh & Eitam, 2015b). One of the key contributions of their research was to replicate the above pattern under conditions in which control motivation actually damaged participants’ overall task performance because they were asked to “respond randomly.” This is because counter to what counted as successful performance of the task (i.e., what counted as positive outcome success), participants’ responses were biased towards keys that were associated with a higher probability to deliver effects (i.e., were more likely to deliver positive control feedback) and away from ones with a low probability to deliver effects. Specifically, participants tended to select the key that was associated with the highest chance to deliver an effect with a higher frequency than they tended to select the key associated with the lowest probability to deliver control feedback--despite this lowering their outcome performance given the task instructions.

This research also found evidence suggesting that the degree of contingency between actions and effects is to some degree accessible to consciousness, and that such awareness is associated with a preference for selecting the key associated with the highest probability of leading to positive control feedback (Karsh & Eitam, 2015a). Conversely, response speed, which Karsh and Eitam (2015b) argued to be more sensitive to the completion of a lower level of response selection (the parameters specifying how a movement is to be performed) was not associated with awareness of action-effect contingency. The modification of these 'low level' action parameters of the action is apparently related to implicit decisions of agency (Eitam et al., 2013; Karsh & Eitam, 2015a; 2015b).

Returning to the comparator model (Blackmore et al., 1999; Frith et al., 2000; Wolpert et al., 1995) with the above in mind, it is possible to draw an analogy between the information generated by the comparator model's first comparator (current state versus motor goal) with what we called outcome feedback (cf. Carver, & Scheier, 1982; Powers, 1973a, 1973b)[2]. In contrast, the source of motivation from control is the (lack of) error signal coming from the third comparator (current *vs*. predicted state)– one that has no counterpart in the classic cybernetic models of goal pursuit, which dealt solely with outcome feedback.

Hierarchical organization of goals, intention and means. Let us now consider how behavior is represented hierarchically in order to substantiate a later claim that, like outcome feedback, control feedback can also target a specific level of abstraction. Goals can be represented at very different levels of abstraction (e.g., Carver & Scheier, 2011; Trope & Liberman, 2010) from 'wanting to be a decent person', to 'donating money to the needy', to

[2] More speculatively, the second comparator may be loosely equated with what Higgins (2012) called 'truth' effectence, or 'truth feedback' in the informational language of Eitam et al., 2013. Here we argue that for control feedback to control behavior this assessment of whether a simulated action vis a vie a goal should generate a "in the right direction" output..

'calling the bank to transfer the money' and so on. Powers (1973a, 1973b) suggested that control systems, which underlie the self-regulation of behavior, are hierarchically organized as superordinate and subordinate goal loops. The more abstract goals (e.g., to be a decent person) residing at the top of the hierarchy, below them abstract principles (e.g., specifying what 'decent' means), followed by specific action programs that are intended to meet the concrete goals that operationalize these abstract principles (Carver & Scheier, 1981, 1982, 2011). Concrete goals may be associated with sequences of actions, which are in turn attained by even lower parameters that operate as low level goals (i.e. configuration, sensation, intensity goals; see Carver & Scheier, 1982; Powers, 1973a). Thus, both very abstract and very concrete goals can serve as reference points for self-regulation.

Behavioral output is determined by monitoring the input information at the adequate level of abstraction and by comparing it to the reference value that is transferred from the level above. To repeat, the behavioral output of a given level serves as the reference value for the next (lower) level (Carver & Scheier, 1982, 1990, 2011; Powers, 1973a). In addition, during the execution of the lower level action, the activation of the higher-level action representation is required (Botvinick, 2008).

Similarly, Searle (1983) distinguishes between *a prior intention* (a goal or reference state) that is independent from the execution of the intended action and an *intention in action* (a lower level implementation) that is sensitive to the internal and external context. Pacherie (2006, 2007, and 2009) develops Searle's classification and defines three stages of intention specification. There are F(uture) intentions that refer to future-directed intentions. Similar to Searle's prior intention, the F intention always will precede (and is orthogonal to) the action itself.

The Intention in action is divided into P(resent) and M(otor) intentions. The P intention is still a relatively abstract intention– the program (Powers, 1973a) or script (Schank & Abelson,

1977) that follows from the F intention. It serves to guide and monitor the ongoing action with sensitivity to the target of the action, to its timing, context and perceptual characteristics. It may be consciously accessed and thus influences one's conscious experience. Lastly, the M (motor) intention is the lowest level or most concrete intention. It translates the perceptual contents of the P intention into a sensorimotor representation "through a precise specification of the spatial and temporal characteristics of the constituent elements of the selected motor program" (Pacherie, 2007, p.3). Conscious access to this type of intention is considered to be limited as it is connected to the details about how the action is performed (Pacherie, 2006). Pacherie (2007) further proposes that the above differentiation between three levels of goals ('intentions') parallels a similar differentiation among three levels of means specificity. The means which serve the most abstract F intentions are represented as subgoals, the means which serve P intentions are represented as specific actions, and the means that serve the M intentions are represented as specific movements.

Another theory that emphasizes an hierarchical representation of goals is action identification theory (AIT, Vallacher & Wegner, 1985, 1987). According to this theory, people tend to construe their actions at one of two levels of abstraction: a 'low level' of identification, which refers to how the action (or what action) is to be performed (i.e., the concrete yet verbalizable aspects of action execution); and a 'high level' of identification in which the action is construed in relation to the goal or the reason for, the why of, performing the action (Wegner at al., 1989).

Control feedback is directed towards different levels of the action hierarchy. There is considerable support for the notion that people represent or frame their actions hierarchically (in addition to the above review, see also Badre, 2010). The abstractness of the goal representation is associated with the process of action selection (Badre et al., 2010). Specifically, most of the models that involve hierarchical loops respect the means-ends hierarchy, such that the type of outcome feedback that is relevant for self-regulation differs according to the abstractness of the corresponding goal (Powers, 1973a, 1973b). Here we propose that the type of *control* feedback also differs according to the abstractness of the goal. Vignemont & Fourneret (2004), for example, distinguish between a sense of agency about an action's execution ("I am the initiator of the action") and the exact manner in which the action is performed ("I am the cause of the action's performance"). Similarly, Pacherie (2006) distinguished between the F intention and the experience of intentional causativeness-- the P intention and the sense of initiation versus the M intention and the sense of control.

Recently, Karsh and Eitam (2015b) suggested that conscious knowledge of one's agency (e.g., knowledge of the best effector to attain control over the environment) was associated with the selection of an effector (a subgoal or specific action according to Pacherie, 2006). In contrast, the implicit decision of agency (another form of control feedback) influenced the selection of low-level motor parameters (the specific nature of the movement).

Thus, similarly to cybernetic models of goal pursuit (i.e., based on outcome feedback), control feedback may also target different levels of abstraction of the action representation. Using Pacherie's (2007) terms, it is possible that the relevant control feedback for the M intention is the 3rd comparator of the comparator model and hence is sensitive to what is relevant to that comparator (e.g., temporal and spatial contiguity; Karsh & Eitam, 2015b). Such 'low-level' control feedback informs the system that it was the one that performed the observed movement (independent of monitoring the attainment of the movement's goal). Similarly, it is possible that different control feedback is associated with more abstract goals (corresponding to Pacherie's P/F intentions).

In the next section we consider how control motivation relates to habitual behavior. We first review some differences between habitual and goal-directed behavior. We then outline our framework for proposing that control feedback is a key mechanism underlying habitual behavior.

Outcome versus Control Motivation and Feedback

Motivation is a theoretical construct that refers to the reasons (or forces) for why people and other animals choose particular actions at particular times and places (Beck, 2000; Lewin, 1935) and persist in performing them in the face of obstacles (Deci et al., 1999; Sansone & Thoman, 2006). In other words, to be motivated is "to have preferences that will direct choices" (Higgins, 2012; p. 24). Studer and Knecht suggest (this volume) that motivation results from an integration of subjective benefits and costs of an activity. In other words motivated behavior is seemingly a product of integration between the value of the reward (objective and subjective) and on its expected demand on resources (e.g., the effort required to attain it; Bijleveld et al., 2012; Kool et al., 2013; Silvestrini & Gendolla, 2013).

Until recently, only outcomes were considered in the computation of subjective reward but based on our exposition above, we propose that reward from control is a second, independent source of value to take into account. Motivation's influence on behavior is classically parsed into two distinct influences: one that refers to the 'direction' of behavior and corresponds to action selection processes; and another, 'energizing' effect, that refers to processes underlying effort allocation, such as the amount of resources that the organism should invest in a behavior (Dickinson & Balleine, 2002; Niv et al., 2006). In this chapter we focus mostly on action selection and how control feedback influences them as an answer to what motivates habits– instrumental behavior that continues to be performed even when the relevant external outcome (for which it was the means) has lost its value.

Tackling a related question, Higgins (2012) describes two classic answers to the question of what motivates people to continue working when goal accomplishment is not immediate (i.e., 'distant outcomes'). The first explanation, the incentives approach, is consistent with the behaviorist framework mentioned above (Beck, 2000; Hull, 1943; Skinner, 1953; Rachlin, 1976). According to this framework people engage in activities instrumentally; with activities construed as a sequence of means to external ends. By this (incentives) approach we do things because we want/need to have the outcomes that we have learned that these activities may bring, or because they can help reduce the probability of unwanted outcomes.

A second possibility is that people continue pursuing an activity due to rewarding properties of the activity itself. By this approach we do things because we like/enjoy/are interested in the ‘activities themselves’. Famously, Deci and Ryan (1985, 2000) highlight the distinction between ‘intrinsic’ and ‘extrinsic’ motivation, with extrinsic motivation referring to external outcomes that control behavior (e.g., money, praise) and intrinsic motivation referring to behaviors that are performed due to their ‘inherently satisfying’ nature (e.g., are fun or challenging).

A timely question is *who or what is 'intrinsically' motivated*. Is it the “organism” (e.g., organismic integration theory; Deci & Ryan, 1985)? Is it the conscious perceiver? Is it a subsystem? Or rather is it a specific representation of an action as is proposed in current models of outcome-based action selection (Redgrave et al., 1999). If the latter, one may further ask at what level of abstraction of the action representation does intrinsic motivation have its effect? A final key question is through what mechanism does an activity *itself* attain rewarding properties?

Relatedly, Higgins (2012) subscribes to a third, hybrid answer to the question of what motivates people when goal accomplishment isn't immediate. The hybrid is that incentives initiate an activity, but once the action has started, valued intrinsic properties are discovered and these “take over” and lead to persistence. By this version, an activity can be at different times extrinsically and intrinsically motivated. What begins as a means to an end takes is no longer tied to the original goal-what Allport (1937) described as becoming "Functionally Autonomous."

Here, we define an 'intrinsically motivated activity' narrowly: as a representation of an activity that has been rewarded due to it being effective in controlling the environment, in making something happen, independent of goal attainment (i.e., by receiving control feedback rather than leading to the attainment of a valued outcome or outcome feedback (Eitam et al., 2013; Karsh & Eitam, 2015a; 2015b). Note that we are not arguing that this exhausts the concept of 'intrinsic motivation,' but rather that control is a-non-outcome dependent motivation, which can to some degree be explained mechanistically.

As we alluded to above, one immediate result of adopting such a mechanistic perspective is that we can offer an explanation of why 'intrinsic motivation' so defined may be hampered by so called 'extrinsic motivation.' It is because outcome feedback (and hence reward from outcomes) will generally trump control feedback (cf. White, 1957). We can also predict when this will *not* be the case, as we describe below.

Habitual versus goal directed behavior. The distinction between goal-directed or purposive and habitual behavior is older than modern (20th century) psychology (e.g., James, 1890). While goal-directed behavior is argued to be pre-planned and flexible, habitual behavior is considered to be reactive and inflexible (Gillan et al., 2015; Wood & Rünger, 2016). Operationally, assessing whether a behavior is goal-directed or habitual is accomplished using a variety of experimental procedures that quantify the sensitivity of the behavior to outcome devaluation (Adams, 1982; Adams & Dickinson, 1981; Balleine, 2005; Balleine & Dickinson, 1998a; Balleine & Dickinson, 1998b; Colwill & Rescorla, 1985; Gillan et al., 2015; Klossek et al., 2008). Such procedures typically include two phases. In the first, an animal learns to select and execute an action that leads to a specific desired outcome. Then, in second phase, the value of the outcome is reduced, such as by using the 'specific satiety' procedure (e.g. Balleine & Dickinson, 1998b) or by inducing an aversion to a food reward (e.g. Adams & Dickenson, 1981; Colwill & Rescorla, 1985). When such interventions lead to a reduction in the frequency of the response that was instrumentally associated with the outcome, the response is said to be goal-directed. Thus, goal-directed behavior is operationally defined as one that disappears after outcome devaluation. Conversely, behavior that continues to be performed at basically the same rate after outcome devaluation is considered to be habitual.

Another common operationalization for classifying goal-directed versus habitual behavior is through testing the behavior's sensitivity to degradation of the (causal) contingency between the behavior and the outcome. Here in the second phase, the desired outcome is given regardless of whether the learned instrumental behavior is performed. Once again, a reduction in the frequency of the behavior is taken as evidence that it is goal-directed (Colwill & Rescorla, 1986; Dickinson & Mulatero, 1989), whereas persistence of the behavior at the same basic rate is evidence for the behavior having become habitual.

How are habits formed and maintained? Previous studies suggest several possible answers to the question of why are behaviors still performed even though they have lost their goal instrumentality. One answer is that habitual behavior is non-motivated behavior, and is the residual behavior following devaluation of a desired goal (Adams & Dickinson, 1981; Adams, 1982; Balleine, 2005; Balleine & Dickinson, 1998b; Bargh, 1994; Wood & Neal, 2007). This is not a satisfying answer. Given that behavior does not typically unfold in a vacuum, it is difficult to understand why a behavior would persist without being motivated in some way. In classic terms, why would it not "extinguish"? Thus, it is more plausible to argue that the habitual behavior continues to be motivated by some source. But what source? According to the 'motivated cueing' approach (Wood & Neal, 2007, 2009), habitual behavior is a 'motivated response disposition' that is activated *directly* through the context cue because that *cue* was associated with positive reinforcement from past performance. This activation can occur without a mediating goal because the goal's reward value has previously conditioned the cue.

Another possible answer is that habitual behavior is a form of goal dependent, yet automatic, behavior operating even when the goal it serves is itself unconscious or automatic (Aarts & Dijksterhuis, 2000). In this case, the context cue activates the goal and the goal automatically activates the corresponding habitual behavior. Importantly, both sources of motivation (the motivated cueing and the goal dependent automaticity) stem from goals (either past or current automatic). In other words, these answers continue to argue that *habits are motivated by outcomes*. And this holds despite the worth of the outcomes being devalued.

Alternatively, one could consider that the habitual behaviors persist despite the worth of the outcomes being devalued because the worth of the habitual behaviors no longer derives from outcomes and, instead, derives from a different motivational system. We propose that the habitual behavior is motivated by an outcome independent source-- by the *degree of control it affords over the environment*, as signaled by control feedback. A unique prediction from this perspective is that analogous to goal-directed behavior being sensitive to outcome devaluation, habitual behavior should be sensitive to control devaluation (e.g., a decrease in control contingency or the worth of having an effect). If supported, this prediction could be a key to future intervention programs for extinguishing unwanted habits. But before considering this, we now consider how an activity might attain such control-related rewarding properties.

The birth of a habit. Our starting assumption is that a hierarchical relation exists between reward from outcome feedback and reward from control feedback (cf. White, 1959). Specifically, as long as outcome feedback is sufficiently precise (in the Bayesian sense of the inverse of the standard deviation), there is a tendency to rely on that information alone to select which action to take. As an example of precise outcome information, when my goal is

100 steps away and I know that I have already walked 60 steps, then I know that 40 more steps will bring me to my goal. Control information has little relevance in such a case.

Given this assumption, we propose that one route for inducing habitual behavior is by reducing the precision of the output of the outcome feedback process. Such a reduction in precision can occur when the outcome feedback (i.e., the input to this comparator) is insufficiently precise, as when it is vague, unreliable, or altogether absent. Alternatively, this reduction in precision can occur by setting continuous, abstract or “infinite” goals (e.g., a 'do your best' goal, see Campion & Lord, 1982; Touré-Tiilert & Fishbach, 2011). This unreliability will lead to lowering the weight of the outcome feedback output for any process that uses it as input, including action selection. Assuming that the weighting of outcome and control feedback in action selection is relative and that these influences compete for action selection, lowering the weighting of the outcome feedback will increase the (relative) weight of control feedback. In other words, such unreliability of the outcome comparator’s output “releases” action selection from the dominance of outcome feedback.

A necessary condition for habit formation is that an action be performed and, typically, repeatedly so. To that end, an action must be deemed relevant and connected to goal attainment (i.e., it must be perceived to be goal relevant). In other words, people need to know about the goal pursuit process, they need to know that they are “moving in the right direction” (Higgins, 2015). This goal relevancy could be derived from either “top down” information from social learning or other prior knowledge or through “bottom up” learning due to repeated rewarding of the response (Thorndike, 1898; Wood & Neal, 2007). Thus, when outcome feedback is imprecise, more attention will be paid to the goal pursuit process itself, to the manner of the goal pursuit, including how an action is executed (or the fact it is executed). That is, they will pay attention to control feedback. This would mean paying less attention to outcomes such as the outcome devaluation that might be occurring, which would lead to habitual behavior.

Let us return to the earlier walking example. If we don't know how much we still have to go, we at least need to believe that every step is a step in the right direction towards the goal. And, if we continue walking, we will *eventually* reach our goal. The lack of precision enables focusing on the execution of the action and leads to positive ongoing *control* feedback in reference to the goal, which simultaneously reinforces the current action– one step at a time.

Empirical results. Recent results from our lab provide initial support for the above proposals. In two experiments, we tested the proposal that a decrease in the precision of outcome feedback will increase the weight of control feedback, and thereby lead to the formation of habitual behavior. The experiments included two phases: an Induction phase and a Testing phase. In the Induction phase, participants performed a bogus creativity task that allowed us to independently manipulate the precision of the outcome performance feedback and the existence of (versus lack of) control feedback given to them (see Table 1). In this phase, participants were told that "the more people are creative, the more they base their judgments on their intuition" and that "in the present task we ask them to tap into their intuitive-subliminal perception skills and guess which letter (S, D, H, J) was subliminally flashed on the computer screen." None actually were, but all but one participant believed that letters were presented. Participants were further told that their goal was to attain 350 creativity points. The probability of receiving 'correct' feedback was manipulated so that each key ("subliminal letter") was associated with a different probability. For example, for one participant pressing the 's' key led to "correct" feedback 90% of the time; pressing 'd' 60% of the time; 'h' 30%; and 'j' never led to "correct" feedback. This assignment was counterbalanced between participants.

[Insert here Table 1 please]

In order to quantify the strength of habitual behavior, the second phase was essentially an outcome devaluation procedure in which the goal of the task was changed to participants being instructed to respond randomly (the EMFC task, Karsh & Eitam, 2015a; 'random' here meaning probability matching; Bar-Hillel, & Wagenaar, 1991). Now, selecting the instrumental action from the Induction phase would actually *damage* performance of the new task (as it would bias specific responses).

Before the testing phase began participants were informed that they are now going to take part in a second task that is also related to creativity but one that will not involve any guessing of subliminal letters. In this second task they were required on every trial to *randomly* select one of the four letters (S, D, H, J). No (outcome) feedback was given on success in being random

In the test participants received own action effects (white flashes) only in the third (of 4) block (a 'saving' block). To test for extinction of the responses from the induction (1st) phase the probability by which a key press led to an effect corresponded to the probabilities for receiving (outcome, control or both) feedback in the induction phase. Thus the key which led to the highest probability to obtain creativity points in the induction phase (an outcome which was now devalued) was associated in the testing phase with the higher probability to deliver control feedback (an action contingent perceptual effect).

To test for our hypothesis that habitual behavior would be sensitive to *control devaluation* (analogous to the sensitivity of instrumental behavior to outcome devaluation), in the first 120 trials of the Test phase we also devaluated control by eliminating the perceptual effect (a white flash), As stated above control (but not value) feedback was reinstated in the next 60 trials in order to examine 'savings'– Note, throughout the testing phase participants' goal was to be as random as possible and there was no feedback on the randomness of performance (see Table 1).

The key finding was that, in the savings block of the testing phase, participants who received imprecise but positive outcome feedback combined with control feedback (a flash) at the induction phase (Condition 5, see Table 1) showed the strongest evidence for habitual behavior. These participants' responses in the saving block were the most biased towards the ("habitual") highest probability for effect key from the induction phase when we reinstated the control feedback (the white flashes). This pattern of results was replicated in a second experiment.

The results also provided preliminary support for the existence of a hierarchical relationship between outcome and control feedback. During the induction phase, when participants received control feedback but were also explicitly told that it was irrelevant to their goal of "attaining creativity points" (Condition 3) their pattern of performance was identical to that of the control group which did not receive any feedback at all. Additionally, these participants did not show any indication of having acquired a habit of pressing the 'high probability key' in the saving block in the Testing phase.

Concluding Remarks

On the one hand, relying on habits is useful because of their automatic, relatively effortless character (i.e., efficiency; James, 1890; Wood & Rünger, 2016). On the other, the same stability makes it difficult to rid ourselves of bad habits. In the present chapter, we tried to shed new light on the motivational force behind habitual behavior and to consider how and when an action attains such rewarding properties.

Several burning questions arise in regard to the proposed framework. To what extent does control-driven habit formation explain dysfunctional habits? For example, might this framework explain some "addictive" behaviors (e.g., email checking)? Can malfunctioning of the hypothesized processes underlie disorders such as obsessive compulsive disorder and impulsive behavior?

One area to which the present framework could be applied is eating disorders, such as anorexia nervosa. The lack of perceived/actual control was associated with engagement in abnormal eating behaviors (Shapiro, 1981; Shapiro et al., 1996) and Strauss and Ryan (1987) have proposed that various “autonomy-related” issues exist in anorexia nervosa. Anorexia could be construed as habitual control over food intake. The creation of such a habit from the perspective of control motivation is as follows: one has a goal to be attractive, to be as thin as you ought to be in order to be attractive. ‘Eating less’ is the dominant means to achieve this goal. The vagueness and open-endedness of this “being attractive” goal leads to the output from outcome feedback being constantly imprecise. This increases the relative weight of control motivation and control feedback, which makes the means of ‘eating less’, and constantly checking on its effects (control feedback) more worthwhile and habitual—independent of any success in becoming more attractive. A possible intervention could be to reduce the worth of control motivation and control feedback by introducing a more precise attractiveness goal and clear outcome feedback, such as tying attractiveness to having a specific weight window determined by height and body type.

To conclude, we have suggested in this chapter that control motivation with control feedback is the motivational force that preserves habitual behavior. Accordingly, we offer a new perspective on habitual behavior. From our perspective, habit is a case where behavior that originates in goal pursuit becomes continuously motivated by control feedback, independent of outcome motivation and feedback. An activity attains such control rewarding properties when the link between it and the goal pursuit outcomes it produces has been weakened. When the output of monitoring one’s outcome attainment becomes imprecise but still considered to be ‘positive’, the relative weight of control motivation and control feedback increases, and control relevant behavior is selected. This, in turn, leads to insensitivity to outcome devaluation and the creation (or manifestation) of habitual behavior.

Above we defined ‘intrinsically motivated activity’ as a representation of an activity that has been rewarded due to it's being effective in controlling the environment (i.e., by receiving control feedback). We further argued that habitual activity is a behavior that is reinforced by control feedback. Is it possible to reverse our argument and also claim that the shift from goal directed behavior to habitual before reflects the shift from extrinsically to intrinsically motivated behavior? Our speculative and tentative answer is ‘no’ – simply because there are other sources which may underlie such a shift (e.g., extensive practice). In fact, it may be the case that further research may differentiate between motivated and non-motivated ‘habitual behavior’.

Further, we are used to use the term ‘habitual behavior’ in the context of the operation of outcome devaluation but our findings suggest, to some degree, that outcome devaluation may merely create the conditions for *revealing* habits. Specifically, but overcoming the default dominance of outcomes in action selection and enabling other forces (e.g., control) to assert themselves.

Conceptually, we are also used to name repetitive behavior as being habitual; this however, again raises the question of what exactly makes this behavior habitual? And the common answer will be: "repetition". Without a better definition we risk circularity. Our proposal of control-motivated habits is one way to circumvent circularity. Further research will show how much of ‘habitual behavior’ can be explained by adopting it.

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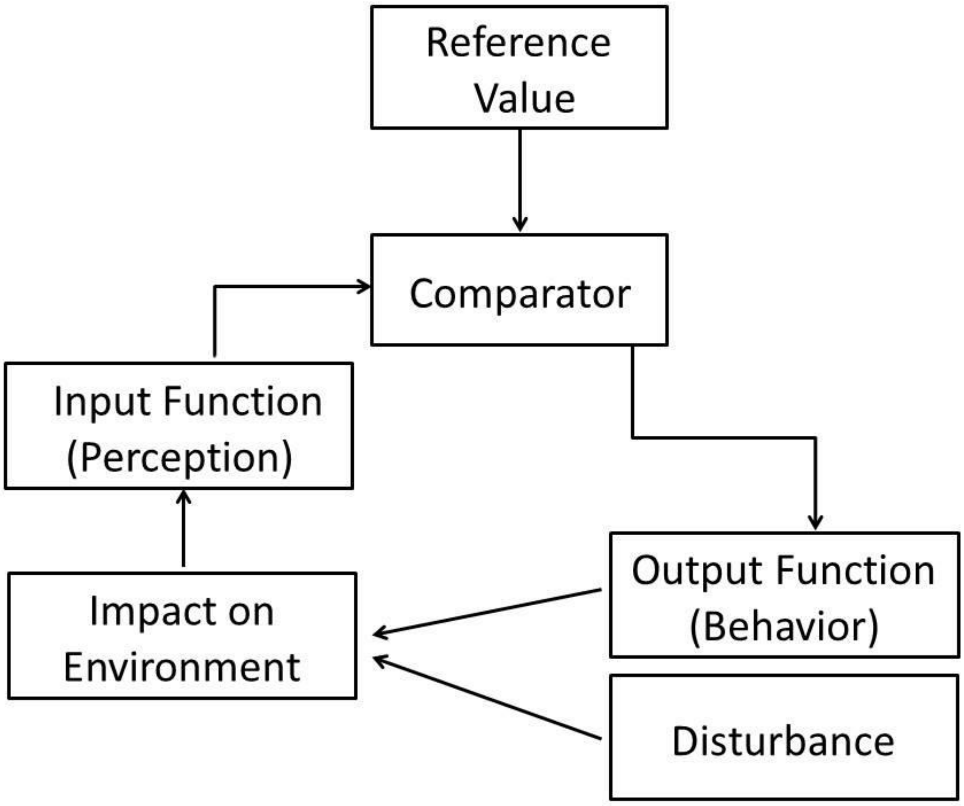

Figure 1: *An illustration of cybernetic model's elements and dynamics (as proposed by Carver & Scheier, 1982, 1990, 2011; Powers, 1973a, b).*

The desired goal / drive serves as the **reference value**; the current state is the **input function**; the **comparator** contrasts the current state with the desired one; **the output function** aims to reduce this gap; this + noise leads to the update of the input function.

Condition	Induction phase			Testing phase	
	Clear Outcome Feedback	Control Feedback	Goal Relevance	Outcome Devaluation	Control Devaluation
1	Running Score	Effect (white “flash”)	Yes A flash equals 1, 2, or 3 points “creativity points”	Blocks 1-4	Blocks 1-2 Block 4
2	Running Score	none	None		
3	none	Effect (white “flash”)	None		
4	None	None	None		
5	None	Effect (white “flash”)	Yes A flash equals 1,2, or 3 points “creativity points”		

Table 1: *The conditions differed in the precision of the outcome feedback and the existence of control feedback.*

Participants in Condition 1 had complete information. Each time they were “correct” they received a white flash (control feedback) and the score was (randomly) raised by 1, 2, or 3 "creativity points". In Condition 2 participants saw the updating score (without an effect). In Condition 3 participants also saw flashes (following key presses) but they were also informed that these were in no way related to their performance, but instead are a test of one version of a computer-human interface. Participants of Condition 4 (a control group), did not receive any feedback. Finally, participants of Condition 5 (the “habit inducing” condition), received a perceptual effect (white flash) every time they pressed a “correct” key. But they were also informed that a white flash might reflect 1, 2 points, or 3 points. This inserted imprecision in the outcome feedback and hence. In the current standing vis a vis the goal.