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Perceptual Control as a Unifying Concept in Psychology

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We show how a control system model of behavior called *Perceptual Control Theory* (PCT) can provide a unifying framework for research in all traditional areas of psychology—as a basis for building hypotheses, working models, and applications. PCT views behavior, at all levels, as the control of perceptual inputs. This view is virtually the opposite of that of now standard models—exemplified by the General Linear Model—which view behavior as controlled by perceptual inputs. The PCT model calls for a new approach to research that is aimed at discovering the input variables that organisms control, rather than the input variables that control organisms. This new approach, called *The Test for the Controlled Variable*, can be applied to the study of all aspects of behavior, from motor control to cognitive neuroscience to counseling and clinical psychology.

Keywords: perceptual control theory, unifying psychology, theory of psychology, perception-action systems, control variables

There are many different areas of psychology and many different theories in each of these areas. Yet, underlying almost all this diversity is a single idea that can be considered the current unifying concept in psychology; the idea that behavior is the last step in a causal chain that begins in the environment or the brain. This causal model of behavior is formalized as the General Linear Model (GLM) of statistics, which is the basis of research in all areas of psychology. According to the GLM, behavior—the dependent variable in most psychological experiments—is ultimately caused by events in the environment—the independent variables in these experiments.[1] The GLM is the reason why textbooks and articles on research methods in psychology say that a properly designed experiment tests whether or not an independent variable is actually the cause of variations in the dependent variable (Cozby, 2009; Levitin, 2002).

The GLM as the Current Unifying Concept

The GLM can be seen to be a unifying concept in psychology because it is the basis of experimental tests of theories in all areas of psychology. Whether one is testing a theory of perception or personality, sensation, or social behavior, the theory is tested in terms of its predictions about whether (and, possibly, how) an independent variable will affect a dependent variable. So a theory of mental rotation is tested by seeing if there is, indeed, a linear relationship between the angular difference between pairs of projective drawings objects (independent variable) and the time it takes to say whether or not the objects are the same (dependent variable), as in the classic experiment in cognitive psychology (Shepard & Metzler, 1971). Or a theory of emotion is tested by seeing whether information about the physiological effects of a drug (independent variable) affects reports of emotional state (dependent variable), as in the classic experiment in social psychology (Schachter & Singer, 1962).

PCT as an Alternative to the GLM

The idea that the causal GLM is the current unifying concept in psychology may seem strange since the alternative appears to be a denial of science itself. But there is an alternative to the GLM that neither denies causality nor the possibility of a scientific understanding of behavior. The alternative is a control model of behavior that was described in a classic paper by William T. Powers (1978) that built upon earlier theoretical work by Powers, Clark, and McFarland (1960a, 1960b). Powers's model is now called *Perceptual Control Theory* (PCT) because it views behavior as a process of controlling perceptual inputs. PCT views organisms as control systems that are acting to maintain perceived aspects of their environment in preselected (goal) states, protected from unpredictable (and often undetectable) disturbances; behavior is the control of perception (Powers, 1973a).

Naturally, cause and effect exists in PCT just as it does in the GLM. However, in PCT causality runs in a circle rather than a straight line resulting in an apparent reversal of the normal chain of events. The difference between the models is shown in Figure 1. The GLM, shown at the top of the figure, assumes that variations in an independent variable (IV) lead to concomitant varia-

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[1] The GLM does not require that the causal connection between independent and dependent variable be linear, which is clear from the fact that the GLM is the basis of statistical tests, like analysis of variance, where the independent variable may not even be quantitative (Cohen & Cohen, 1983).

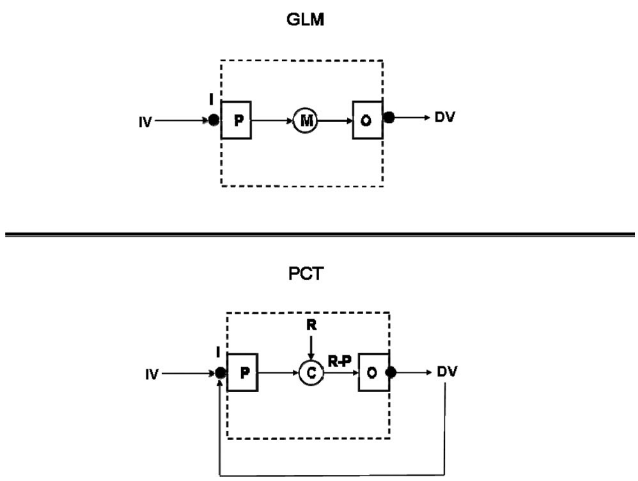

Figure 1. Functional flow diagrams of the General Linear Model (GLM) and Perceptual Control Theory (PCT) models of behavioral organization. The dotted-line boxes denote the boundaries of the organism. IV = independent variable; I = input; P = perception; M = mental processing; O = output generators; DV = dependent variable; C = comparator; R–P = reference specification–perceived value.

tions in sensory input to the organism (I). Processes inside the organism (perception, P, mental processing, M, and output generators, O) convert these sensory inputs into the behavioral outputs that are the dependent variable (DV) in experiments. Different versions of the GLM—the different psychological theories in different areas of psychology—posit different mechanisms for P, M, and or O, the psychological processes inside the organism. Sometimes these psychological processes are thought to be quite complex, involving loops and branches. But causality is always assumed to move in a one way path from IV to DV.

The PCT model, which is shown at the bottom of Figure 1, differs from the GLM only in that it takes into account the feedback effect of the organism's output, O, on its own sensory input, I. In PCT causality runs from sensory input to motor output and, simultaneously, from motor output to sensory input. The organism exists in a closed-loop of causality where sensory input, I, is simultaneously a cause and effect of output. The effect of sensory input on output depends on the difference between the perceived value of this input, P, and a reference specification for this perceived value. The reference specification is shown as R in Figure 1 and the function (called the *comparator*) that computes the difference between R and P is the circle labeled C.

If the feedback effect of an organism's output on its sensory input is to reduce the difference between the reference and the perceived value of that sensory input (i.e., to minimize C), then the closed-loop of causation is a negative feedback loop and the organism in such a loop is a control system. Powers (1978) showed that the behavior of such a control system is organized around the control of P, the perceived value of sensory input: as per the title of Powers' book on the topic, *Behavior: The Control of Perception* (Powers, 1973a). The perceived aspects of the organism's sensory input that it controls are called *controlled variables*. The sensory input variable, I, in the lower part of Figure 1 can be thought of as the sensory correlate of the controlled variable.

A control system keeps I under control by varying its outputs (seen as the DV in the lower part of Figure 1) to counter environmental disturbances (the IV in the lower part of Figure 1) that would "push" the controlled variable, I, from the reference state, R, selected by the organism itself. To an outside observer there will appear to be a causal relationship between IV and DV but the relationship between IV and DV is actually one of disturbance resistance—the DV resisting the disturbance to the controlled variable caused by the IV—and the relationship ceases to exist as soon as the organism stops controlling I.

The Inevitability of Feedback and the Behavioral Illusion

Many psychologists who use the GLM as the basis of their research recognize the existence of feedback in behavior but assume that these feedback effects can be disconnected from the effects of input on output. If this were true, then it would be possible to study input–output causation without interference from feedback and the GLM would be a valid basis for the unification of psychology. And it does seem like the feedback link from output to input is disconnected in the typical psychology experiment, in the sense that the DV in these experiments has no effect on the IV.

But a closer look shows that feedback exists in all psychological experiments, making every experiment a control task. This can be illustrated using a simple reaction time (RT) experiment where it appears that the onset of a stimulus light (IV) causes the key press response (DV). Although there is no feedback link from DV to IV in this task (the key press response has no effect on the light) there is a link from the DV to the perceived relationship between IV and DV. Indeed, the participant is asked to control this relationship, pressing the key (DV) only when the stimulus light (IV) comes on and not pressing otherwise. So the controlled variable in the RT experiment is a logical relationship: If the light is on AND the key is pressed OR the light is off AND the key is not pressed then the relationship is TRUE, otherwise it is FALSE. The participant is asked to keep this relationship TRUE. If the participant were not instructed to control for this perception, turning the light on and off would have no apparent effect on responses.

The instructions given to the participants in an experiment define the perception(s) to be controlled: the controlled variable(s), I. The IV in the experiment (such as the light in the RT experiment) is a disturbance to I; the DV is the means used to keep I at the reference level. The feedback connection is from DV to I; the effect of output (DV) on input (I) in experiments is inevitable; it cannot be eliminated.

The Behavioral Illusion

The inevitability of feedback in psychology experiments means that the use of the GLM to analyze the results of these experiments will be misleading (Powers, 1978; Marken, 2009). The results of the typical psychology experiment do show some relationship between an IV and a DV, as shown in the graph on the right in Figure 2. If the organism under study fits the assumptions of the GLM (the main assumption being that there is no feedback from DV to controlled variable, I, as in the upper part of Figure 1) then the observed relationship between IV and DV would be correctly interpreted as telling us something about the causal processes that

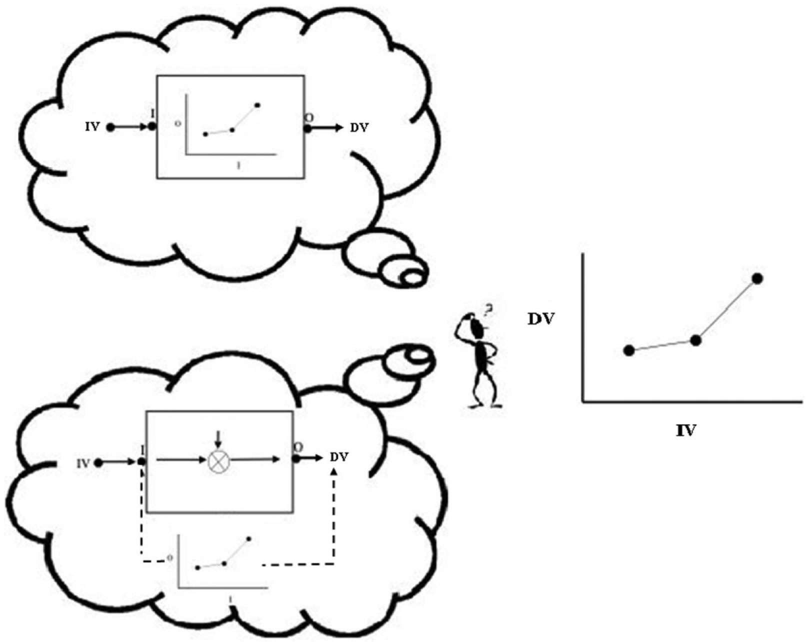

Figure 2. The behavioral illusion. The conventional interpretation of an experimentally determined relationship between and independent variable (IV) and dependent variable (DV) is that it reflects characteristics of organism that transform sensory inputs into behavioral outputs (upper thought cloud). If, however, the organism under study is a control system the observed relationship between IV and DV is the inverse of the feedback connection from DV to controlled input, I (lower thought cloud).

connect input to output as shown in the top "thought cloud" on the left of Figure 2—the causal processes that make up the mind (M) in the causal model at the top of Figure 1.

If, however, the organism under study is a control system then the observed relationship between IV and DV tells us very little about the causal processes between input and output. In fact, the relationship between IV and DV is determined mainly by characteristics of the feedback function that connects the DV to I, the variable that the participant is controlling in the experiment, as shown in the bottom "thought cloud" on the left of Figure 2. This surprising fact about the relationship between IV and DV that is observed when studying a control system has been called the *behavioral illusion* (Powers, 1973b; Cziko, 2000).

The behavioral illusion implies that the results of psychological experiments may be misleading, not that they are useless. In fact, if the organisms under study are control systems then a relationship between an IV and a DV will be observed only when the IV is a disturbance to perceptions that are being controlled by these organisms, using the DV as the means of control. The finding of such an effect is not an end-point, but a starting point for the identification of what specific perceptual variables the organism is controlling.

Methodological Implications of the Control Model: The Test for the Controlled Variable

PCT shows that understanding the behavior of control systems—human or otherwise—is a matter of identifying the perceptual variables that organisms control: controlled variables. Although conventional experimental methodology can be used to show that some variable is under control, a new methodology is needed to determine what these variables are. This new methodology is known as the Test for the Controlled Variable (TCV; Runkel, 2003; Marken, 1997; Marken, 2009).

The TCV shares many of the basic features of conventional psychological experimentation. For example, the TCV starts with a hypothesis about what will be observed in the experiment. However, although the hypothesis in a conventional experiment is about a causal relationship between variables, the hypothesis in the TCV is about what variable is under control. The TCV also involves manipulation of an IV. But whereas the aim of conventional experiments is to see if there is an effect of the IV on a DV, the aim of the TCV is to see if there is lack of an effect of the IV on the hypothesized controlled variable (CV).

The basic idea behind the TCV is that a variable that is under control will be protected from disturbances that would otherwise cause it to vary. The IV in the TCV is a disturbance that would be expected to cause variations in a variable that is not under control. If the IV does not cause the expected variations in the variable, then it is evidence that this variable is, indeed, under control. If the IV does cause the expected variations then the hypothesis that the variable is under control is rejected and a new hypothesis is tested. The TCV continues until one finds a definition of the CV that is protected from the effects of all disturbances (IVs). For example, you might guess that a person is controlling the distance between the two of you. If not, then moving toward or away from the person (the IV) will cause proportional variations in this distance. If so, then the IV will have little or no effect on this distance as the person moves to compensate for these disturbances in order to maintain the desired interpersonal distance.

The TCV as a Unifying Methodology in Psychology

The TCV is the basic methodology that is used to study the controlling carried out by organisms. If organisms are, in fact, control systems, then the TCV can serve to unify scientific psychology. In the following section, we will illustrate where the assumptions underlying the TCV approach have been used implicitly or explicitly across different fields of psychology.

Perception and Motor Control

Many studies using the TCV have involved computerized tracking paradigms (e.g., Marken, 1980, 1989, 1991). These paradigms mimic the key component of a wide variety of everyday perceptual motor tasks such as writing, aiming, and steering. In these experiments, the participant uses the mouse or a lever to control specific features of a visual display despite disturbances that are caused by the computer.

For example, in one study the participant was instructed to keep the size of a target rectangle that varied in height and width over time matched to the size of a comparison rectangle (Marken, 1989). The participant controlled the size of the comparison rectangle by varying its width (using the mouse) to compensate for variations in its height. A version of the TCV was used to determine what perception the participant was actually controlling when controlling size. Two possibilities were tested: perimeter and area. The TCV was carried out by looking at the relationship between variations in height (the disturbance to the CV) and width (the output that compensates for the disturbance). If perimeter was the CV then this relationship would be linear; if area was the CV then this relationship would be quadratic. The relationship was found to be quadratic, indicating that the CV in this situation was the area of the rectangle.

Some early studies of perceptual-motor behavior that have used methods similar to the TCV were based on the ecological approach to perception (Gibson, 1966). In a now classic study, Lee and Aronson (1974) used a test very much like the TCV to show that infants control visual variables to maintain their balance. They were able to demonstrate that suddenly disturbing visual orientation could “topple over” a standing infant. Apparently the infant was controlling (unsuccessfully when it fell) for alignment with its visual perception of vertical.

More contemporary perceptual motor research has attempted to distinguish the perceptual variables that are controlled to walk toward a target and avoid obstacles. For example, Warren and Fajen (2009) performed a range of intricate studies using a Virtual Environment Navigation Lab (VENLab) to test various hypotheses about the controlled variable when walking toward a target in an obstacle filled environment. Using computer-generated disturbances to the optical consequences of walking in the VENLab, the researchers were able to determine that the CV in these studies was textural flow, rather than location in the visual field.

A particularly clear application of the TCV has been used in the area of object interception research. Theorists have proposed three different hypotheses regarding the perceptual variables controlled when intercepting objects such as such as baseballs or Frisbees: linear optical trajectory (LOT; McBeath et al., 1995), vertical optical acceleration and lateral movement (OAC; McLeod et al., 2001) and vertical optical velocity and lateral movement or COV (Marken, 2001). Ingenious research by Shaffer et al. (2004), using Frisbees to disturb optical trajectories, ruled out the strict LOT hypothesis. Marken (2005) has discussed ways to use the TCV to hone in on the correct definition of the perception(s) being controlled in object interception and produced a working computer model to simulate the COV explanation.

Animal Behavior

There is a little known heritage of early studies that have explored controlled variables within the field of animal behavior (for a review, see Pellis & Bell, 2011). For example, Berkenblit, Feldman, and Fucson (1986) studied wiping behavior in frogs: They are able to remove adhesions from a front leg by wiping it using their back leg. When the experimenter applies a disturbance by moving the front leg to a different position, the frog targets the same location on the leg to remove an adhesion, even though this involves different motor output. Thus, the experimenter is testing whether the adhesion location is the controlled variable; by disturbing the orientation of the limb and observing that the disturbance is ineffective it can be concluded that perceived adhesion location is, indeed, controlled.

Recently, the study of animal behavior has been extended and refined using the TCV to test for controlled variables in the behavior of crickets and rats (Bell & Pellis, 2011; Pellis, Gray, Gray, & Cade, 2009). Bell and Pellis (2011) used time-lapse video recordings to explore the variables controlled when a rat with food attempts to avoid having the food pellet stolen by a “robber” rat. They hypothesized that one controlled variable was the distance between the two animals. To test this hypothesis, they repeated trials with different starting distances. As predicted, the motion of the robber rat (the angle it traversed) was not correlated with the interanimal distance (because this was kept constant), but it was correlated with the motion of the “dodger” rat. This research was repeated across contexts and within individuals to converge on a similar result, which indicated that the dodger’s actions were the means through which it acted against the movement of the robber rat to keep the food at a controlled distance from the robber.

Personality and Social Psychology

An example of the TCV in the field of personality psychology relates to the finding that people tend to resist attempts by other people to describe them in ways that are not consistent with their self-image, a process often termed self-verification (Swann, 1983). Two studies involved eliciting participants’ own self-descriptive terms and then, in a second stage of the study, describing the participant in terms that contradicted these self-descriptions. In line with the hypothesis that self-image is a controlled variable, the participants attempted to correct the experimenter when the descriptions were inconsistent with their self-image (Robertson et al., 1999).

Organizational Psychology

Within the field of organizational and work psychology, Vancouver and colleagues have used the TCV in a range of different paradigms (e.g., Vancouver & Zawidzki, 2007). For example, Vancouver et al. (2008) developed a computer task that involved creating the work schedules for nurses in a hospital and in tandem created a computer model that could be programmed to complete the task using different controlled variables. By comparing the match between participant-generated data and computer-generated data, they could infer which variables were being controlled by the participants. Using this method, they demonstrated that the participants were not controlling their behavior (such as shifting a nurse from one time allocation to another) instead they were controlling the layout of the schedule itself with their behavior as the means to achieve this goal.

Developmental Psychology

During development, the perceptual variables that an organism is able to control are likely to change as they develop. Plooij (1984) investigated this systematically using the TCV in a naturalistic study of the development of infant chimpanzees in the wild. The development of control was seen in the effect of disturbances to possible controlled variables produced by a developing chimp's mother. For example, infant chimps are apparently born without the ability to control the sensations (warmth gradient) that get them to the nipple. In this case, the mother's actions help the infant locate the nipple. Once the infant has developed the ability to control nipple-locating sensations the mother's actions become a disturbance that is resisted by the infant. The wise chimp mother can detect this resistance and the "helping" (that is no longer helping) ceases altogether.

PCT and Advanced Research

Although the studies described above do not always use all the features of the TCV, they are all aimed at understanding behavior in terms of the perceptual variables that organisms control. That is, they are all consistent with the idea that observable behavior is a process of controlling perceptions. The range of areas covered by these studies is consistent with the idea that all behavior, from maintaining one's balance to maintaining one's self-concept, is a process of control. These studies show that the concept of control can serve as the basis for research in all areas of psychology.

The idea that all behavior can be seen as a process of control is central to the PCT model of organisms (Powers, Clark, & McFarland, 1960a, 1960b; Powers, 1973a, 2008). PCT views individuals as a hierarchy of control systems, with lower level systems controlling simple perceptions, such as muscle forces and joint angles, whereas higher level systems control complex perceptions, such as "honesty" and "democracy." The theory also includes a specialized learning algorithm (known as reorganization) that allows control systems to adapt and optimize their control. The theory is specified in sufficient mathematical detail to make it possible to build computer models to test its premises. These models have been used to carry out the TCV by generating a close match with the behavioral data. Some pertinent examples include a hierarchical model of the control of the distance between pairs of lines (Marken, 1986), a multiagent model of collective behavior in crowds of people (McPhail et al., 1992), a robotic model of rhythmic mimicry for use in psycholinguistics (Moore, 2007), and a multilevel model of goal striving for use in organizational psychology (Vancouver, Putka, & Scherbaum, 2005). Recently, PCT has also been used in the development of psychological therapies and in research on psychopathology (Carey, 2008; Higginson, Mansell, & Wood, 2011).

Conclusions

We have proposed that humans and other organisms are purposeful: They control their sensory inputs. Therefore, they need to be studied using a methodology that is designed to test for these controlled perceptual variables. This methodology, the TCV, has already been applied successfully across different fields of psychology, and we therefore proposed that it represents a unifying approach to the study of psychology. Furthermore, this approach paves the way for a theory of behavior (PCT) that can be used to build valid models that have wide applications. Indeed, this theory may be so widely applicable because its principles are core to the way that living organisms are organized, and the principles are general enough to apply to the full range of phenomena that psychologists are interested in.

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