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You Say You Had a Revolution: Methodological Foundations of Closed-Loop Psychology

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To the extent that a scientific revolution represents a fundamental change in a discipline, the cognitive revolution in psychology was not particularly revolutionary. What changed least in this revolution was methodology. The experimental methods used in cognitive psychology are the same as those used in the behaviorism it overthrew. This methodological continuity results from the fact that both behaviorism and cognitive psychology are based on the same paradigm, which is also the basis of experimental psychology: the open-loop causal model of behavioral organization. A truly revolutionary approach to understanding the mind has been largely ignored because it is built on a paradigm that is inconsistent with conventional research methods. This new approach to psychology, called Perceptual Control Theory (PCT), is based on a closed-loop control model of behavioral organization that is tested using control engineering methods that are unfamiliar to most psychologists. This paper introduces the methodological foundations of closed-loop psychology, explains why the closed-loop revolution has not happened yet, and suggests what psychology might look like after the revolution has occurred.

Keywords: experimental psychology, research methodology, causal model, closed-loop psychology, control theory

Thomas Kuhn (1962) published his influential treatise on scientific revolutions at about the same time that scientific psychology started going through a revolution of its own. It was a time when revolution, scientific and otherwise, was in the air. Kuhn described a scientific revolution as a significant shift in the fundamental theoretical framework or "paradigm" of a discipline. The revolution in psychology involved a shift from the behaviorist paradigm, which views psychology as the study of observable behavior, to the cognitive paradigm, which views psychology as the study of mental processes. There is now some consensus that this shift was, indeed, revolutionary and it has been dubbed the "cognitive revolution" (Dember, 1974; Gardner, 1987; Mandler, 2002; Miller, 2003).

Although there was much about the cognitive revolution that was revolutionary, there was also much that was not. What was revolutionary was the development of theories of mind, especially coming at a time when the behaviorist paradigm viewed such theories as nonscientific. What was not revolutionary was the way cognitive research was done. The methods used by cognitive psychologists to study the mind are the same as those used by behaviorists to study behavior while ignoring (or denying) the mind.

Experimental Psychology

There are many different ways to do research in psychology, including surveys, correlational studies, and quasi-experiments. However, the gold standard for research in psychology is the experiment. The typical psychology experiment involves manipulation of a variable in an organism's environment as the independent variable (IV) while measuring some aspect of the organism's behavior as the dependent variable (DV). When an experiment is done properly, so that all possible confounding variables are held constant, an observed relationship between the IV and DV is taken as evidence that the environmental variable is a cause of variations in the behavioral variable. This approach to experimental research in psychology can be called *causal methodology* because the goal is to determine the causes of behavior (Levitin, 2002).

The results of an experiment using causal methodology can be represented in a graph like that in Figure 1, which shows the average value of the DV at each of the different levels of the IV. These results could have come from an experiment performed by a behaviorist before the cognitive revolution or by a cognitive psychologist after it. For example, the IV could be the size of the reinforcement that follows a bar press and the DV could be running rate in an operant conditioning experiment, as in a classic experiment of behaviorism (Teitelbaum, 1957). Or the IV could be the angular difference between pairs of perspective drawings of objects and the DV could be the time to say "same," as in a classic experiment of cognitive psychology (Shepard & Metzler, 1971).

Both the behaviorist and the cognitive psychologist would quite reasonably see experimental results like those in Figure 1 as evidence of a causal relationship between the IV and DV. The behaviorist sees these results as evidence that the size of reinforcement (IV) causes variations in the rate of running (DV) and the cognitive psychologist sees them as evidence that the angular difference between the perspective drawings of objects causes the variations in the time it takes to say "same." Clearly, the experimental methodology and the conclusions drawn from it are the same for both the behaviorist and cognitive psychologist, and for good reason: both behaviorism and cognitive psychology are based

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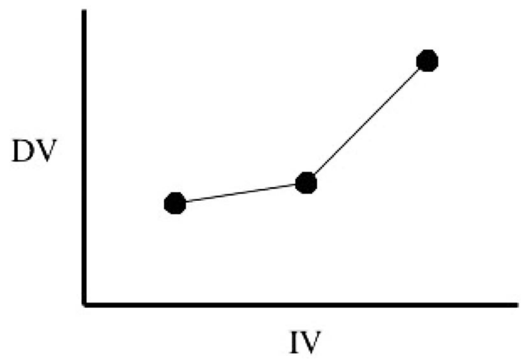

Figure 1. The results of a typical experiment using causal methodology. The IV is an external environmental variable and the DV is a behavioral output variable. Average values of the DV are shown for each level of the IV.

on the same open-loop causal model of behavioral organization that is also the basis of experimental research in psychology.

Open-Loop Causality

The open-loop causal model is shown in Figure 2. It is also known as the General Linear Model, which is the basis of the statistical analysis of experiments in psychology (Cohen & Cohen, 1983). The model assumes that behavior is the last step in a causal chain that begins with variations in an environmental variable in the world outside of the behaving system and ends with variations in behavior. The environmental variable causes variations in the sensory input, I, to the system, ultimately causing variations in the behavioral output, O, from the system. The behaving system itself is viewed as a "transfer function" that converts sensory input into behavioral output. The graph inside the box labeled "system" represents this function. The model is "open-loop" because it assumes that causation runs in a one-way path from environmental input to behavioral output; the system's output does not "loop back" and affect its input.

Causal methodology is based on the assumption that organisms are organized according to the open-loop causal model. In an experiment using causal methodology, the IV is typically an environmental variable and the DV corresponds to a behavioral variable. The goal of experiments based on this model is to determine the causes of behavior, which means determining the nature of the organism transfer function. Essential to the validity of this approach is that the causal path from IV to DV be one-way or open loop. Only if this is the case can any observed relationship between the IV and DV be considered a reflection of the nature of the organism transfer function in Figure 2. Researchers of all theoretical persuasions who use causal methodology must assume, therefore, that organisms are organized as open-loop causal systems. Because both behaviorists and cognitive psychologists use causal methodology, the open-loop causal model should be apparent in the theoretical narratives of both behaviorism and cognitive psychology, and, indeed, it is.

Open-Loop Behaviorism and Cognitive Psychology

The open-loop causal model is explicit in the stimulus-response or S-R approach of behaviorism. According to S-R theory, environmental stimuli (S) cause behavioral responses (R) via the organism. The organism itself is treated as a "black box" where what goes on inside the box is of less concern than observable relationships between stimulus inputs into the box and response outputs from it. The goal of research in behaviorism is to discover these S-R relationships, which are the "laws of behavior."

In cognitive psychology, the open-loop causal model of behavior shows up as the computational theory of mind, which is nicely described by Pinker (1997):

> ". . . beliefs and desires are information, incarnated as configurations of symbols. The symbols . . . symbolize things in the world because they are triggered by those things via our sense organs . . . If the bits of matter that constitute a symbol are arranged to bump into the bits of matter that constitute another symbol in just the right way, the symbols corresponding to one belief can give rise to symbols corresponding to another belief logically related to it, which can give rise to symbols corresponding to other beliefs, and so on. Eventually the bits of matter constituting a symbol bump into bits of matter connected to the muscles, and behavior happens." (Pinker, 1997, p. 25).

This description suggests that the processing that goes on between input and output can be quite complex, with many loops and branches. However, this processing ultimately goes in one direction, starting with information about external environmental variables ("things in the world") and ending with behavioral output that "happens" at the end of this open-loop causal chain.

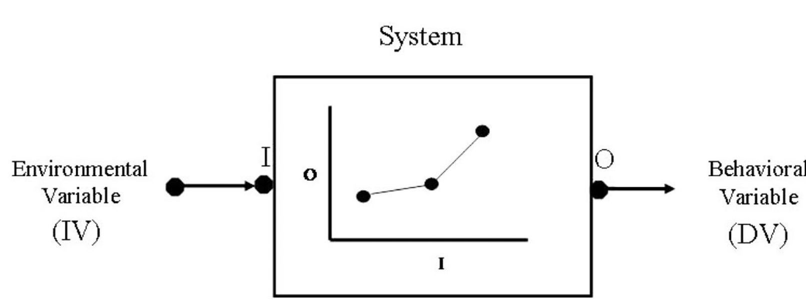

Figure 2. The open-loop causal model of behavioral organization. External environmental variables cause sensory inputs, I, that cause behavioral outputs, O. The system is a transfer function that converts the sensory inputs, I, into behavioral outputs, O. An example transfer function is shown inside the system.

Normal Science and Paradigm Shifts

The open-loop causal model is a scientific paradigm in the sense that it is a theoretical framework for understanding the basic subject matter of psychology. It is also a paradigm in the sense that it defines what constitutes the practice of "normal science" in psychology (Hoynongen-Huene, 1993; Kuhn, 1970). Because both behaviorism and cognitive psychology are based on this paradigm, the cognitive revolution required no change in the conduct of normal science. It was possible to change from behaviorist to cognitive psychologist without having to change anything about how one went about the business of doing psychological science.

The cognitive revolution would have been a much harder sell if it had required that psychologists change the way they do normal science. We can see this by looking at the reception accorded a theory of behavioral organization that did require such a change. The theory, which is now called Perceptual Control Theory (PCT), was developed by William T. Powers and his colleagues (Powers, McFarland, & Clark, 1957) and later described in detail by Powers in his book *Behavior: The Control of Perception* (Powers, 1973c). PCT came along at the height of the cognitive revolution. However, it has been largely ignored, possibly because it requires a completely new approach to the practice of psychological science.[1] PCT is based on a new theoretical paradigm that cannot be tested using causal methodology. The new paradigm is a closed-loop control model of behavioral organization.

Closed-Loop Control

The closed-loop control model is shown in Figure 3. The model is very similar to the open-loop causal model except that it explicitly shows the behavioral output of the system, O, looping back to affect the sensory input, I. The effect of output on input is called *feedback*. Although reading the diagram from left to right makes it seem like the feedback effect of output on input occurs *after* the "feed-forward" effect of input on output, feedback and feed-forward are actually occurring at the same time. Variations in input are causing variations in output *while* variations in output are causing variations in input. This corresponds to real life situations, such as driving a car, where one's view of the location of the car relative to the road (sensory input) is causing steering wheel movements (behavioral outputs) that are simultaneously influencing the view that is causing those movements.

Because feedback and feed-forward occur simultaneously in a closed-loop system, the behavior of the system must be defined by two simultaneous equations rather than by a single equation as in the open-loop causal model. One equation describes the feed-forward path from input to output, which is the same as the organism transfer function for an open-loop system. The other describes the feedback path that goes through the environment from output to input.

When the feedback in a closed-loop system is negative, such that the effect of output on input is to reduce the effect of input on output, the solution of the simultaneous equations that define the system's behavior shows that the system acts to *control* its input (Powers, 1978). Control involves varying system output to maintain an input variable at a prespecified goal or reference value, protected from *disturbances*. Disturbances are external environmental variables that cause variations in sensory input that tend to "push" that input away from the reference value. The outputs of a closed-loop negative feedback system "push back" against these disturbances in order to keep the sensory input at the reference value. Because the function of a closed negative feedback system is to control its input, the closed-loop model of behavioral organization is called a *control* model.

The desired or reference value of the input controlled by a closed-loop control system is specified inside the system itself by a *reference signal* like the one shown in Figure 3. Reference signals represent the cognitive component of the closed-loop control model. These signals function as intentions in the sense that they specify desired or goal results of the system's actions. The variables controlled by closed-loop control systems are actually perceived aspects of the sensory input to those systems. For example, one of the many aspects of sensory input that is controlled when one drives a car is the perceived distance between the front of the car and the middle line in the road; another is the perceived speed of the movement of the car relative to other cars. The aspect of the sensory input that is controlled by a closed-loop control system is, therefore, a perceptual representation of that input. Thus, the behavior of a closed-loop negative feedback control system can be described as "the control of perception," as in the title of Powers' landmark text.

Causal Methodology and Closed-Loop Systems

IV as Disturbance

When experiments based on causal methodology are used to study a system that happens to be closed-loop, then the IV is actually a disturbance to the input controlled by the system, as shown in Figure 3. If the DV is the output that protects the input from these disturbances then the result of an experiment on a closed-loop system using causal methodology will be a clear relationship between the IV and the DV, such as that in Figure 1. This relationship reflects the disturbance resistance that is characteristic of the behavior of a closed-loop control system. When a disturbance pushes a controlled input variable in one direction the output of the system pushes back in the opposite direction. Therefore, a strong negative relationship between IV and DV will typically be observed when causal methodology is used to study a closed-loop control system (Powers, 1978).

Powers (1973a) showed that the nature of the relationship between disturbance (IV) and output (DV) variations that is observed in experiments on closed-loop systems depends on characteristics of the environmental feedback function that connects system output (DV) to controlled input (I) and not on characteristics of the behaving system itself. This is because the feedback function determines how much output the system must produce to counter the effects of any disturbance (IV) to the controlled input. For example, the amount of force (output) that a bicyclist must produce

[1] Kuhn himself did not ignore Powers' work. Asked to review the manuscript for the 1973 book, he provided this comment for the book jacket: "Powers' manuscript, *Behavior: the control of perception*, is the most exciting I have read in some time. The problems are of vast importance, and not only to psychologists . . . I shall be watching with interest what happens to research in the directions to which Powers points." He did not see the research in his lifetime.

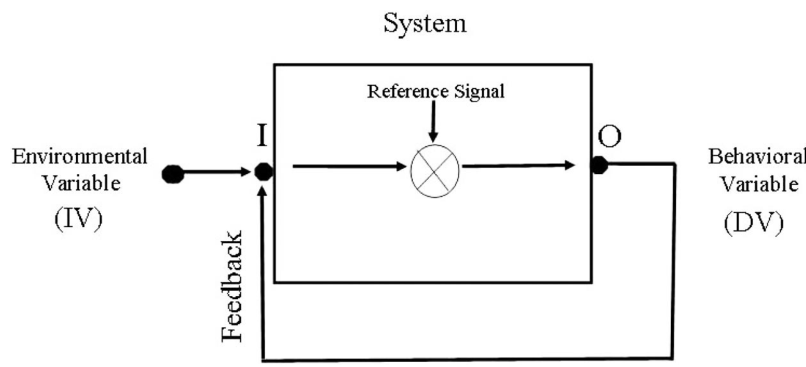

Figure 3. The closed-loop control model of behavioral organization. Sensory inputs, I, cause behavioral outputs, O. At the same time, behavioral outputs have a feedback effect on the sensory inputs that are causing those same outputs. There is a circle of cause and effect that runs from I to O via the organism (the feed-forward path) and from O to I via the environment (the feedback path). The result is that the system acts to keep I matching an internal reference specification, protected from disturbance caused by the environmental variable (IV). This process is called control.

to stop a bike using handlebar brakes will differ depending on the wetness of the road. A change in wetness changes the feedback connection between brake squeeze force (output) and the perception of stopping (input), resulting in a change in the relationship between disturbance (such as a pedestrian moving into the bike's path) and output (the squeeze force exerted by the bicyclist on the brake). The bicyclist will appear to have become more responsive as the wetness of the road increases. Nevertheless, the change is in the environment (wetness of the road), not the bicyclist.

So, when causal methodology is used to study closed-loop systems, an observed relationship between the IV and DV may actually reflect characteristics of the environmental feedback connection between a system's output and input rather than internal properties of the system itself. This surprising and counterintuitive fact about the results of experiments on closed-loop systems gives rise to what has been called the "behavioral illusion" (Cziko, 2000). Powers first described the behavioral illusion and its implications in a paper that appeared in *Science* in 1973 (Powers, 1973a). In a response to comments on that paper, Powers said the following: "If control system theory does indeed correctly describe the relationship between organisms and their environments, behaviorism has been in the grip of a powerful illusion since its conceptual bases were laid" (Powers, 1973b). Unfortunately, the same can now be said of cognitive psychology as well.

Closed-Loop Methodology

It is impossible to tell whether organisms are open or closed-loop systems by simply looking at the IV-DV relationships obtained using causal methodology. Such relationships will be observed whether the system is open or closed-loop. A new approach to doing psychological research is needed only if organisms are in fact closed-loop systems. Therefore, the first step in the closed-loop revolution in psychology must be to determine whether organisms are organized as open or closed-loop systems. It is possible to do this by performing the appropriate tests, which apply methods adapted from control engineering. The most important of these methods is called the test for controlled variables or TCV (Marken, 1997).

The TCV is the basic methodology for studying living control systems. It is based on control engineering techniques designed to measure the quality of control in man-made closed-loop control systems, such as the thermostat. Man-made control systems are designed to keep certain variables at preselected values, protected from disturbances. The thermostat, for example, is designed to keep the temperature of the air in a room at a preselected value, such as 70° F, protected from disturbances, such as variations in outside air temperature. The input variable controlled by the control system is called a *controlled variable* (CV). Room temperature is the CV of a thermostat. A control system controls well to the extent that it keeps the CV close to the preselected or *reference* value of that variable over time despite disturbances.

What psychologists want to know about control systems is somewhat different than what control engineers want to know. While control engineers want to know how well a system controls a known CV, psychologists want to know whether the system under study is, in fact, a closed-loop control system and, if it is, what variables it is controlling. The TCV can be used to answer both of these questions.

The TCV, as adapted for use in psychology, starts with a hypothesis about a CV. For example, consider a beaver building a dam. One hypothesis might be that a variable controlled by the beaver is the loudness of the noise of flowing water; the beaver might want to keep the noise level at zero dB. Water noise is, thus, a hypothesized CV. The next step in the TCV is to see if the system acts to protect the hypothesized CV from disturbances. If water noise is a CV then disturbances will have little or no effect on the perceived noise level. If, on the other hand, disturbances do have an effect then water noise is not under control.

Amplifying the sound of water near the beaver is one way to produce a disturbance to perceived water noise level. If this disturbance increases perceived water noise level then water noise is not under control. If, however, this disturbance has very little effect on perceived water noise level—because, for example, the beaver is piling material around the loudspeaker, keeping the noise level at zero dB—then the hypothesized CV may be under control. The TCV continues until the experimenter is convinced that all disturbances that should affect the hypothesized CV have little or no effect on it, at which point the experimenter can tentatively conclude that the variable is, indeed, under control.[2] Although the TCV has never been systematically done on dam building behavior, observations suggest that beavers might, indeed, control water noise level, along with other variables, by building dams (Richard, 1983).

In the process of determining whether a particular variable is controlled, the experimenter is also implicitly determining whether or not the system under study is a closed-loop control system, at least with respect to the variable that is hypothesized to be the CV. If the TCV rules out a hypothesized CV as being under control then the system is not organized as a closed-loop control system, at least with respect to that variable (Marken, 1997).

Closed-Loop Versus Causal Methodology

The TCV differs from causal methodology mainly in its aims. The aim of causal methodology is to find the environmental variables that cause system behavior; the aim of the TCV is to find the sensory inputs that are controlled by the behaving system. However, besides the difference in aims there are also some important differences in procedure. One difference is that the TCV is used to test one individual at a time rather than groups of individuals (Runkel, 1998). The TCV is not a statistical approach to understanding mental processing based on measuring the average performance of groups of individuals. In addition, whereas causal method methodology looks for an effect of external environmental variables on behavioral variables, the TCV is aimed at finding a *lack of effect* of these variables on a hypothetical controlled variable. The TCV recognizes that, if the system under study is closed-loop, then external environmental variables are likely to be disturbances to input variables that are being controlled by the system.

The focus of the TCV is always on the discovery of controlled variables rather than on the discovery of relationships between environmental and behavioral variables. If the system under study is closed-loop then all possible relationships between environmental and behavioral variables can be deduced once the researcher knows the variables the system is controlling and how environmental and behavioral variable affect the state of these variables.

Finally, because the TCV is used to study closed-loop control systems, the proper use of this methodology requires a good "feel" for how control systems work. This "feel" comes from a clear understanding of the nature of control and, in particular, the nature of a CV (Marken, 2001).

We All Want to Change the World

If control theory is right and organisms are, indeed, closed-loop systems then why has the closed-loop revolution not happened yet? One reason may be that the results of experiments using causal methodology are exactly what would be expected if organisms are open-loop causal systems; variations in an IV seem to cause concomitant variations in a DV. Because there is nothing surprising about the results of conventional psychology experiments psychologists have seen no reason to suspect that these results might be misleading (as per the "behavioral illusion" described above). Control theory, itself, suggests why this would be the case: even if organisms are closed-loop control systems, psychological experiments using causal methodology will produce results, like those in Figure 1, that are completely consistent with what is expected based on the open-loop causal model.

Another reason why there has been no revolution may be because there has been no *experimentum crucis* in psychology, comparable to the Michelson and Morley (1887) experiment in physics, that demands reconsideration of the foundations of the discipline. There has been no closed-loop revolution because there seems to be no reason to revolt. Nevertheless, there are several observations that, taken together, suggest that there might be reason for a cautious reappraisal of, if not open rebellion against, the current approach to doing research in psychology.

Cause of Behavior

The closest thing psychology has to a Michelson-Morley experiment may be Powers' (1979b) demonstration that causality does not work as expected in a closed-loop control task. The demonstration involves a simple compensatory tracking task where the participant is asked to keep a cursor aligned with a fixed target by moving a handle to compensate for an invisible disturbance to the cursor's position. Powers showed that the correlation between cursor variations and handle movements in this task is close to zero while that between invisible disturbance variations and handle movements is on the order of $-.99$. This result is surprising from the point of view of the open-loop causal model because cursor variations are the only possible cause of the handle movements; cursor variations are the only variable that can tell the participant how to move the handle in order to keep the cursor on target. Although correlation does not imply causality, lack of correlation does strongly suggest lack of causality. Therefore, absence of a correlation between cursor variations and handle movements in this simple tracking experiment leads to the paradoxical conclusion that the only possible cause of the behavior (handle movements) in this task is not the cause of that behavior.

In an attempt to resolve this paradox, I repeated the compensatory tracking experiment using a procedure that would make it possible to determine whether there was *anything* about cursor variations that could be considered the cause of handle movements (Marken, 1980). The procedure was based on the fact that the handle movements in these tracking tasks are almost perfectly negatively correlated with disturbance variations. By repeating the same disturbance variations on two different trials, the participant produced nearly identical handle movements on those trials. If

[2] Some critics have suggested that the TCV reveals no more than what could be revealed about a closed-loop system using causal methodology. It has been claimed, for example, that one can tell that a thermostat is controlling room temperature by observing the relationship between an IV, such as changes in the heat produced by a heater near the thermostat's sensor, and a DV, such as changes in the heat output produced by the thermostat's furnace. Although it is true that such a relationship will be observed for a thermostat that is controlling room temperature, it will also be observed for a system that is controlling some other variable, such as humidity. The only way to tell what variable a system is actually controlling is to use the TCV.

something about the cursor variations is the cause of handle movements, then cursor variations on those trials should also have been highly correlated, but they were not.

The behavior in a compensatory tracking task occurs in a closed-loop: cursor variations affect handle movements while handle movements affect cursor variations. The studies by Powers (1979b) and Marken (1980) show that the open-loop causal model of behavior cannot explain closed-loop behavior. Nevertheless, these studies have had little impact, perhaps because the results are not obviously relevant to anything other than perceptual-motor control tasks. However, there is reason to believe that these results have more general implications because much of what we see as "behavior" seems to be closed-loop inasmuch as it involves control, which is a closed-loop process (Marken, 1988). For example, a complex behavior like "playing chess" involves making moves to "control the center." However, even if all behavior is not closed-loop the possibility that some might be should encourage researchers to at least test this, using the TCV, before going on to study the behavior using causal methodology.

Statistical Results

One of the most obvious signs that there might be something wrong with the open-loop causal model is the fact that the results of research using causal methodology are extremely noisy, so much so that statistical analysis is a standard component of the analysis of the results of any psychological experiment. The random component of the variation in the DV observed in the typical psychology experiment is so large that statistical tests must be used to decide whether any apparent effect of the IV was real or due to chance. When it can be concluded that an IV does have an effect, it rarely accounts for more than 30% of the variance in the DV. This kind of result suggests that behavior is highly variable with a large random component. However, Runkel (2003) points out that this level of random variability is not at all evident in everyday behaviors such as walking and driving a car. For example, people rarely take a step and fall. However, this kind of success requires enormous behavioral consistency. Even if the probability of a successful step were as high as .999 a person walking at 100 steps per minute would fall once every 10 minutes (Runkel, 2003, pp. 167). If behavior were anywhere near as variable as it appears to be in conventional psychological experiments we would see people falling all the time; in fact, we do not.

Control theory suggests that the apparent random variability seen in experiments using causal methodology could come from looking at behavior the wrong way, as open rather than closed-loop. If behavior is, indeed, a closed-loop process than much of the apparent random variability in behavior could be because of systematic differences between organisms in terms of variables that are ignored by causal methodology, specifically, controlled variables and the varying reference specifications for these variables. Some evidence that these factors may be contributing to the apparent random variability of behavior comes from the fact that research using closed-loop methodology, which does take controlled variables and varying reference specifications into account, typically accounts for over 96% of the variance in observed behavior (e.g., Marken, 1986). This level of predictability could become commonplace when closed-loop methodology becomes standard procedure in scientific psychology.

Establishing Operations

One way to characterize the difference between open and closed-loop systems is that the former have no purpose while the latter do. The purpose of a closed-loop system is to keep perceptual variables in reference states. Therefore, purpose determines how and, indeed, whether a closed-loop system will react to disturbances, which are the IVs in experiments using causal methodology. Purpose shows up as the "establishing operations" given to participants in such experiments. Establishing operations, such as the verbal instructions given to humans or the deprivation regimens given to animals, give participants a purpose inasmuch as they encourage the participant to control a particular perception. For example, the participants in the mental rotation study were instructed to have the purpose of saying, as quickly as possible, whether two perspective drawings were of the same object or not. The participant is being asked to control for a relationship between what they say ("same" or "different") and what they see and to do this as quickly as possible. Unless the participant adopts this purpose, the IV (angular difference between objects) will have no apparent effect at all on the DV; pairs of perspective drawings do not ordinarily lead people to say "same" or "different" as quickly as possible.

Purpose in the form of establishing operations is an essential part of every psychology experiment. If it were not, psychologists would not be able to find any relationship between an IV and a DV using causal methodology. Carrying out a purpose is equivalent to controlling a perceptual variable: bringing it to a specified reference state while protecting it from disturbances (Powers, 1978). The fact that the participants in all psychological experiments must be instructed to carry out a purpose if the experiment is to work at all suggests that these participants are closed-loop control systems. What is usually not clear is exactly what purpose the participants are carrying out. In control theory terms, what we do not know is exactly what perceptual variables the participants are trying to control. As noted above, much of the apparently random variability in conventional psychological experiments may result from the fact that each participant in a conventional psychology experiment may be controlling a somewhat different perception, even though each was given exactly the same instructions.

While the correlations observed in tracking tasks, the noisy relationships between IV and DV and the need for establishing operations are not proof that organisms are closed-loop systems, they are strong evidence of that possibility. These characteristics of contemporary scientific psychology have not been enough to set off a revolution but they should at least be enough to encourage a careful reevaluation of the validity of the open-loop causal basis of experimental research in psychology.

Co-Opting the Revolution

It is hard enough to have a scientific revolution when all that is involved is a change in theory, but it's nearly impossible to have one when it also requires a fundamental change in the way one goes about the business of doing research. To most scientific psychologists causal methodology *is* the scientific method. Therefore, many psychologists who have become interested in the closed-loop approach to psychology have assumed that the proper way to test the theory is with causal methodology. Carver and

Scheier (1981, 1998) provide a case in point. These researchers developed a model of "self-regulation" that is explicitly based on Powers' control theory model of mind. They clearly and correctly described the closed-loop organization of their self-regulation model but they have tested it using causal methodology, looking for causal relationships between external environmental variables and behavioral output variables. Therefore, their research methods are based on the assumption that the organisms under study are organized as open-loop causal systems, contrary to the predictions of their own theory. If, indeed, organisms are closed-loop control systems, then the use of causal methodology is revealing more about the environments in which people "self-regulate" than about the mental process that are involved in self-regulation.

The psychologists who have co-opted the closed-loop revolution have done so by embracing the idea that organisms are closed-loop systems whereas acting as though such systems can be studied using causal methodology. This co-opting is surely unintentional, resulting from the fact that all psychologists are trained to look at behavior through "open-loop glasses," which make it appear as though causal methodology is the only conceivable way to do science (Marken, 2002a). Through open-loop glasses, the closed-loop control model appears to be completely consistent with the prevailing open-loop paradigm. The result is that the closed-loop revolution has not happened and causal methodology is still the main approach to doing psychological research, even when psychologists are testing closed-loop models of behavior (e.g., Jagacinski & Flach, 2002; Smith, Flach, Dittman, & Stanard, 2001).

The closed-loop revolution in psychology cannot begin until psychologists start using a methodology like the TCV, which recognizes the possibility that organisms are closed-loop control systems. Before this revolution occurs, it might be useful to imagine what scientific psychology will look like when it is based on a closed-loop control model of behavioral organization.

Closed-Loop Psychology

The main goal of a closed-loop approach to psychology would be to determine the kinds of perceptual inputs organisms control. PCT assumes that organisms control a hierarchy of different types of perceptual variables (Powers, 1973c). The lowest level perceptions in the hierarchy are what psychologists have called sensations. These are perceptions such as the loudness and pitch of sound or the brightness and hue of light. Higher-level perceptions are often called cognitions. These are perceptions of variables such as the level of honesty of a sales pitch or the degree to which one has control of the center in a chess game.

Research in closed-loop psychology would be aimed at discovering what perceptual inputs organisms control when they are carrying out certain activities. One example of such research is the study of how people catch fly balls (Babler & Dannemiller, 1993; Dienes & McLoed, 1993; McBeath et al., 1995; Tresilian, 1995). The goal of this research is to determine the visual variables that are controlled (the CVs) when a person moves to catch a ball. Several hypotheses have been proposed regarding the variables controlled when catching balls, including the optical trajectory, acceleration and velocity of the ball (Marken, 2001). So far, the appropriate tests to determine which of these variables is actually controlled have not been performed (Marken, 2005). Nevertheless, research in this area gives a very clear picture of what a closed-loop psychology would look like. Researchers understand that catching a ball is a closed-loop process that is organized around the control of perceptual input variables (CVs). Moreover, in at least one case, something very much like the TCV has been done using the variable path of a Frisbee as a disturbance to a hypothetical CV (Shaffer, Krauchunas, Eddy, & McBeath, 2004).

Another example of research aimed at discovering the perceptual inputs organisms control is found in the study of two-handed coordination (Mechsner, Kerzel, Knoblich, & Prinz, 2001). In a series of ingenious experiments, Mechsner and his colleagues have shown that coordinated movement is organized around the control of the perceptual consequences of hand movements. Although more research is needed to determine the CVs involved in two-handed coordination tasks, Mechsner and his colleagues have shown that two-handed coordination—that appears to involve the open-loop generation of hand movements—is a closed-loop control process. The perceptual variables controlled in this loop are visual and proprioceptive consequences of hand movements. Closed-loop research on two-handed coordination should be aimed at determining what these variables are.

The perceptual variables controlled when catching a ball or making coordinated movements will probably be found to be at a relatively low level in the perceptual control hierarchy. Robertson, Goldstein, Mermel, and Musgrave (1999) have shown how the TCV can be used to determine whether people control higher-level perceptions such as "self image." These researchers applied disturbances, in the form of words that were thought to be either consistent or inconsistent with the self-image a person was trying to control. The researchers were able to predict with great accuracy the words that would be rejected as inconsistent with and those that would be accepted as consistent with the hypothesized self-image, showing that individuals do control a variable that represents a higher-level perception of themselves.

Powers (1992) has also shown how the TCV can be used to test for control of a cognitive variable. The research was done as a simple tracking task where the goal was to keep the name of a U.S. president—the target name—displayed on the screen while disturbances act to change the displayed name to that of a previous or subsequent president. To compensate for this disturbance it was necessary to move a handle in the correct direction to restore the target name to the display. To maintain control the subject had to remember the order of the presidents that preceded and followed the target. Subjects were able to do this, demonstrating their ability to control a high-level concept through the use of information stored in memory.

I have done research aimed at determining the hierarchical relationships between lower-level sensation-type perceptions and higher-level cognitive-type perceptions that are proposed in Powers' PCT model of mind (Marken, 2002b, p. 85–112). This research is based on the assumption that the control loops involved in controlling lower level perceptions are faster than those controlling higher-level perceptions. This difference in speed is a basic stability requirement for a hierarchical organization of control systems, as demonstrated in models of hierarchical control (Powers, 1979a). Using the exact same "stimulus" variables presented at different speeds I have found evidence for a hierarchy of controlled perceptions ranging from very fast control of configuration (shape) perceptions (controlling for a square rather than some other shape) to the much slower control of sequence perceptions (e.g., controlling for shapes appearing in a particular sequential ordering of size).

Besides testing for controlled perceptual variables, the study of closed-loop cognition would also have to tackle traditional topics like remembering, thinking, and imagining. Closed-loop studies of these topics would focus on the purposes involved in carrying out these activities. Control is an inherently purposeful activity (Marken, 1990) because it involves acting to achieve a prespecified goal result or purpose. Studies of remembering, for example, might be aimed at determining a person's purpose when trying to memorize a set of items, as in a simple free-recall task. Questions addressed by this research might be: Is the person doing the recall task trying to remember every item, just the most recently presented items or items from the beginning of the list? Hypotheses about the purposes involved in cognitive tasks are hypotheses about CVs that exist only in the mind. Testing to determine whether these mental CVs are actually under control will require the development of innovative new ways of doing the TCV.

How to Have a Revolution

The closed-loop revolution in psychology will be truly revolutionary, which means that it will require a radical change in how scientific psychology is practiced and taught. One might hope that it would be possible to make an evolutionary rather than a revolutionary transition from an open to a closed-loop psychology, thus minimizing the discomfort that would result from such a revolution. However, it is impossible to gradually change from one paradigm to another. There is no compromise possible between an open and closed-loop view of organisms, just as none is possible between round-earthers and flat-earthers. One either uses causal methodology, assuming an open-loop system, or the TCV, assuming a closed-loop system. There are no conceptual or methodological steps in between.

The move to closed-loop psychology, when it happens, will be like starting psychology all over again, based on a new foundation: the closed-loop control model of behavioral organization. If, while pursuing the new psychology, we find useful or suggestive results obtained from the old one, so much the better. Nevertheless, the focus must be on doing a new kind of research that is appropriate for the study of closed-loop control systems. This research would be aimed at mapping out the perceptual variables that individual organisms control.

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