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The Origins and Future of Control Theory in Psychology

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The construct of "control" is virtually ubiquitous in psychology and it links to a comprehensive range of real-world outcomes. Control theory is critically important in this regard because it describes and models the dynamic systems that enable control to occur. Yet, the origins and principles of control theory in psychology are often misunderstood. This leads to a failure to capitalize on its strengths as a unifying, dynamic framework. We address this gap in knowledge by describing the early origins of control theory and its 2 main paths of development within psychology, as a "man−machine system" approach, and as a "grand theory" of psychology. We introduce the grand theory approach to control theory, pioneered by William T. Powers (1926-2013). Powers (1973) proposed that behavior is the control of perception and he introduced a closed-loop, hierarchical architecture to implement this principle. We propose that Powers' control theory provides a wholly new perspective on psychological science and is, as such, a third grand theory, after the behaviorist and cognitive theories. We describe a range of advances in neuroscience, animal behavior, social processes, and mental health, based on Powers' theory, to illustrate its potential to transform the nature of psychological research and practice.

Keywords: self-regulation, unified theory, research methodology, control theory

Given the level of influence currently enjoyed by control theory-based theories of behavior (e.g., Carver & Scheier, 2012; Vancouver & Weinhardt, 2012), now seems like a timely point in the history of psychology to write an article on the origins and nature of the application of control theory in psychology. Control theory provides an explanation of how control works, both in nonliving and living systems. Control has emerged as maybe one of the most important concepts in psychology. *Control* is widely proposed to be at the heart of successful childhood development (self-control; Moffitt et al., 2011), physical health and mortality (perceived control; Infurna, Ram, & Gerstorf, 2013), and resilience (attentional/effortful control; Taylor, Eisenberg, Spinrad, & Widaman, 2013). Yet, maybe owing to its pervasive importance, multiple groups of researchers have used the term. The plethora of uses of the term *control* presents a huge challenge. As early as the mid-1990s, over 100 uses of the term *control* were identified within the psychological literature (Skinner, 1996). Yet most psychological theories involving control assume that the reader understands what the term means; they provide neither an operational definition nor an explanation of its mechanisms. Thus, a theory of control itself appears pivotal as a tool for clarifying such a situation.

An account of control theory in psychology is also timely because psychologists are increasingly aware of the benefits of eschewing traditional, lineal, causal theories about the mind to embrace dynamic, embodied models of psychological functioning (e.g., Chemero, 2011; Friston, 2010). Control theory provides such a model and it is becoming increasingly relevant to contemporary behavioral science (Carey, Mansell, & Tai, 2014; Carver & Scheier, 2012; Pellis & Bell, 2011; Vancouver & Weinhardt, 2012). Yet, despite its huge potential breadth of use, control theory is consistently misunderstood in terms of its origins and principles, even by many of those who attempt to use the theory. A notable widespread error has been to locate the origins of control theory within social psychology during the 1980s. Such an error is not only an issue of intellectual accreditation, but it obscures the conceptual clarity gained through knowledge of the foundations of the theory. This article aims to clarify the epistemological and conceptual inaccuracies that have arisen regarding the application of control theory in psychology. We also take this opportunity to raise awareness of the ever-increasing relevance of control theory for psychology by describing some of the most recent empirical studies in this field.

Control and Control Theory

Control processes have been identified and used at many points in history. Within biology, Walter Cannon's (1932) notion of *homeostasis* is an example of a control process (Carpenter, 2004). Cannon's work built upon Claude Bernard's concept of the *milieu intérieur*—the maintenance of a stable internal environment of the cells of the body—that he developed as early as the mid-19th century. Yet, control theory itself originated in the field of engineering, and a number of devices that control, called *control systems*, have been developed through history. One is a water tank, attributed to the ancient Greek inventor Ktesibios, that keeps itself filled at a constant level despite variations in evaporation rate. Another is the fly ball governor, attributed to James Watt in the 19th century, which maintains a constant engine speed despite

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varying loads. The theory of how these systems work appears to have been fully formalized in the 1920s by electrical engineer H. S. Black (see Black, 1977). Control systems are devices that keep variables in preselected (goal) states, protected from disturbances, such as the effect of varying evaporation rates on water level or the effect of varying loads on engine speed. Perhaps the most familiar modern example of a control system is the home thermostat, which keeps a variable, room temperature, in a prespecified goal state, such as 68 °F, protected from disturbances, such as variations in outdoor temperature. Thus, the behavior of a control system can be described as goal-oriented (or purposeful), and control theory can be seen as an explanation of how to build systems that exhibit such behavior. Since psychologists from the time of William James (1890) have been aware of the goal-oriented, purposeful nature of behavior, it is not surprising that there have been many efforts to bring control theory into psychology.

Control Theory in Psychology

We distinguish two main approaches to applying control theory in psychology. These can be called the *grand theory* and the *man−machine systems* approaches and they both emerged at nearly the same time, in the 1940s. The grand theory approach views control theory as a general model of all behavior, much like the stimulus−response (S-R) model of behaviorists or the information-processing model of cognitive psychologists. The man−machine systems approach, on the other hand, views control theory as a tool for analyzing human performance in closed-loop tasks, much like information theory is used as a tool for analyzing the results of perceptual experiments (e.g., Attneave, 1954). We explain the meaning of *closed loop* in the next sections. The grand theory approach is commonly attributed to Wiener (1948), who introduced the cybernetic perspective on behavior and marked a period when a number of cyberneticists began to influence psychology (e.g., Ashby, 1952; Ruesch & Bateson, 1951; Rosenbleuth, Wiener, & Bigelow, 1943). This is a grand theory approach because it was based on the idea that all behavior is goal-oriented, and control theory is the theory that explains this. Another work in the grand theory approach that is familiar to many psychologists is the Test-Operate-Test-Exit (TOTE) model of Miller, Galanter, and Pribram (1960). The beginning of the man−machine systems approach, on the other hand, is arguably attributed to Craik (1947, 1948) and continues in the field of engineering psychology (e.g., Sheridan & Ferrell, 1974; Wickens, Hollands, Parasuraman, & Banbury, 2012).

Although the man−machine systems approach has been successful as a tool for analyzing human performance in subfields of psychology, such as human factors engineering (Hancock et al., 2013; Jagacinski & Flach, 2002), the grand theory approach seemed to have lost appeal in psychology by the 1970s. But the grand theory approach seems to have been regenerated in the form of self-regulation theory (e.g., Carver & Scheier, 1982; Vancouver, 2000; Vohs & Baumeister, 2011). We shall now explain how the origins of a substantial body of work within the field of self-regulation theory can be traced back to the control theory model of William T. Powers (1973). Powers actually started developing the theory in the 1950s (Powers, Clark, & McFarland, 1960a,1960b). Yet, the theory, now known as *perceptual control theory* (PCT), gained little traction in psychology until it was adopted by two social psychologists, Charles Carver and Michael Scheier, in an article in *Psychological Bulletin* (Carver & Scheier, 1982). They described several elements of Powers' (1973) theory in its original, unmodified form and explained its potential for social and clinical psychology. Nonetheless, Carver and Scheier misrepresented some fundamental features of PCT (e.g., by proposing that it is behavior rather than perception that is controlled). They have gone on to explore their own version of Powers' theory (e.g., Carver & Scheier, 2001) that now bears much less resemblance to PCT.

Speculatively, Powers may have not achieved the recognition for his own theory because he was not a psychologist (he worked as a control engineer and did not have a PhD in psychology), or because some of the tenets of PCT conflicted with some basic assumptions of the other grand theories of psychology (Marken, 2009; Powers, 1978). But whatever the reason, some of the principles of PCT—though, unfortunately, not PCT itself—have begun to emerge in the guise of self-regulation theory. We propose that PCT now takes its place along with cognitive and S-R as one of the grand theories of human behavior. We give a brief description of PCT, show how it differs from the other grand theories, and give some examples of the application of PCT to understanding behavior.

Behavior as Control

PCT differs from other grand theories in its assumption about the nature of behavior itself. Both S-R and cognitive theories treat behavior as outputs that are emitted by an organism. For example, both theories would treat a button press (a behavior used in research based on both S-R and cognitive theories) as the result of efferent neural impulses that cause the muscle forces that move the finger to press the button; the button press is seen as the last step in a causal chain that starts in the nervous systems and ends in the observed behavior: the button press. But Powers realized that any behavior is a combined result of the actions of the behaving system along with characteristics of the environment in which the behavior is produced. The button press depends not only on the finger pressing on the button but also on the resistance force of the button, the orientation of the finger relative to the button and so on. What this means is that different muscle forces (and, hence, different efferent signals) are needed on different occasions in order to produce a consistent result—the button press. Different means are required to produce the same result on different occasions due to variations in the circumstances prevailing at the time the behavior is produced. So when a person produces a consistent result, such as a button press, on different occasions, they are doing it by varying the means of producing this result —varying their muscle forces—just the right way so as to compensate for the changing circumstances that would prevent this kind of consistency. Powers recognized that what we are seeing whenever we see a consistently produced result, is control.

Control can be seen as a process of achieving goal results in the face of disturbances (changing circumstances) that would otherwise prevent achievement of these goals. So, pressing a button is a goal-oriented behavior inasmuch as a goal is consistently achieved (the button is pressed) in the face of varying disturbances (changing friction of the button and orientation with respect to the button). PCT was developed as an explanation of how goal oriented behavior (control) works. It works because the goal result is part of a negative feedback control loop—a closed loop—as shown in Figure 1. The controlled variable in this diagram is the variable aspect of the environment that is prevented from varying by the control system's output. The goal specification for this variable is inside the system in the form of a reference signal, $r(t)$. The perceived value of the goal result, $p(t)$ is compared continuously with the goal specification and any discrepancy is an error signal, $e(t)$ that drives outputs that affect the state of the goal results. If the system is properly designed so that the error drives the output in a way that pushes the controlled variable, and thus the perception of the controlled variable, toward the goal specification, then the goal result will be produced. So, for example, in the case of the button presses, the goal state, $r(t)$ is to perceive the button down; if the button is not down there is an error that drives the output, $o(t)$, the muscle forces, that press the finger down on the button. These forces will bring the button to the reference state (down) regardless of the state of disturbances, $d(t)$, to the button.

Figure 1 is a functional diagram of a control system—a system that achieves goal results in the face of disturbances. It does this by acting so as to bring a perception of the goal result to the goal state. So behavior—in the example the behavior called button press—is the control of perception, as per the title of Powers' (1973) classic book, *Behavior: The Control of Perception.*

Putting Goals Back into the Organism

An important aspect of the PCT model in Figure 1 is that it places the specification for the goal state of a behavioral result inside the organism itself (inside the dotted box marked in the figure). This placement of the goal specification—the reference signal—results from Powers' understanding of behavior as a process of control; the organism must specify the intended state of the behavioral result in order to control it. But placement of the goal specification inside the behaving system is largely unique to the PCT application of control theory to understanding behavior. All other applications of control theory in psychology, whether in the grand theory or man machine system approach, place the goal specification outside of the behaving system, as shown in Figure 2, outside the dotted box. This placement of the goal specification is consistent with the prevailing view of how organisms work; organisms are thought to be input−output devices, and so the perceptual input (which is the perceived difference between goal and actual state of the behavioral variable, $e[t]$) is thought to drive output. In the button press task described earlier, the button pressed down is thought of as the goal specification, $r(t)$ and the current position of the button, $y(t)$ is the output that is compared to this goal specification outside of the system. The error is the difference between $r(t)$ and $y(t)$ that is thought to be converted by a *transfer function* within the human, Y_H. This signal then drives the button movement via a further transfer function within the machine or "plant," Y_P.

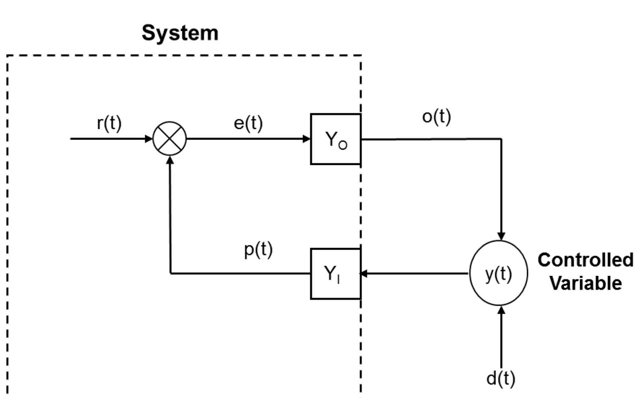

Figure 1. Perceptual control theory (PCT) model of a control system; control theory for psychologists. Adapted from *Control Theory for Humans: Quantitative Approaches to Modeling Performance* (p. 160), by R. Jagacinski and J. Flach, 2002, Mahwah, NJ: Lawrence Erlbaum. Copyright 2002 by Taylor & Francis. Reprinted with permission.

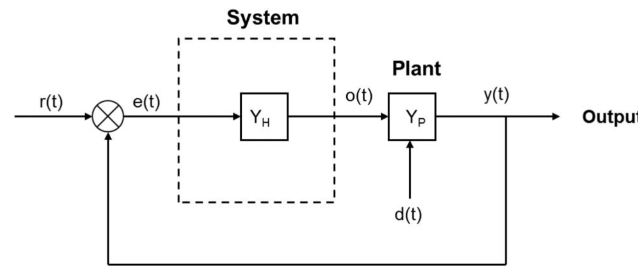

Figure 2. Diagram of control system with goal specification outside the behaving system. Adapted from *Control Theory for Humans: Quantitative Approaches to Modeling Performance* (p. 160), by R. Jagacinski and J. Flach, 2002, Mahwah, NJ: Lawrence Erlbaum. Copyright 2002 by Taylor & Francis. Reprinted with permission.

Clearly, placing the goal specification outside of the behaving system is incorrect. But because doing so has been, and continues to be, consistent with the prevailing view of how organisms worked, the PCT view of control, with the goal specification inside the system—specifying the state of a perception rather than an output—has been largely ignored. So, the grand theory of behavior as the control of perception (as illustrated in Figure 1) needed to be brought back into psychology. This occurred within the field of self-regulation theory (e.g., Carver & Scheier, 1982). Perhaps the idea became acceptable because calling it *self-regulation* made it more palatable. Instead of talking about control, the self-regulation theorists talk about regulation; and instead of talking about control of perception, they describe regulating the self. So substituting the word *self* for *perception* and *regulation* for *control* has arguably made the self-regulation version of PCT palatable as a theory of behavior. But this change in terminology reflected a change in the theory as well. The terms *perception* and *control* have precise meaning in PCT and refer to essential features of the model. Using substitute terms may make verbal descriptions of PCT more palatable but obscure the true nature of the theory and how to test it (Marken, 2009). Although self-regulation theorists may have brought Powers' work to the attention of a wider audience, it was left to those who then went directly to Powers work to test, model and disseminate it more comprehensively.

PCT: The Third Grand Theory

Arguably, PCT can be considered to have joined S-R and cognitive theory as one of the main grand theories of behavior.

This third grand theory gives us a very different picture of how behavior works. According to PCT, when we see people doing things—behaving—we are seeing them 'from the outside' controlling aspects of their own inner, perceptual experience. In order to understand behavior we have to understand what perceptions people are controlling. For example, to understand what people are doing when they intercept objects, we have to determine which aspects of their optical perceptions are under control (Marken, 2005; Shaffer, Marken, Dolgov, & Maynor, 2013). To understand how people adjust schedules, one has to know what they are controlling when they are filling out these schedules (Vancouver & Scherbaum, 2008). A series of studies since the late 1970s have tested the PCT account through a moment-by-moment analysis of disturbances, controlled variables, and action within individuals during tasks that involve tracking objects (e.g., Marken, 1980, 1986, 1991, 2005, 2013; Powers, 1978). Consistently, these studies show that actions oppose disturbances to control the perceptual variable that is required in the task (e.g., the distance between moving objects). This enables computer models of the task to be constructed with a high level of correspondence with the behavioral task (*r*s $>$.95).

PCT also explains why behavior often looks like it is caused by external stimuli and why it also sometimes seems to be emitted output. Behavior looks like it is caused by external stimuli when a disturbance to a controlled variable is seen as a stimulus, the compensating output is seen as a response and the controlled variable goes unnoticed. This is often what happens when the disturbance is sudden - in reflexes such as the eyeblink. According to a PCT model, the puff of air is a disturbance to the moistness of the cornea; the blink is a compensating response to remoisturize the cornea and the controlled variable is, of course, the moisture level on the cornea. Behavior also seems to be emitted output when all that is observed is the controlled variable. This might happen when we observe the position of the legs when walking. Yet, while we are walking, the muscle forces are compensating for disturbances such as changes in the grade of the terrain. Yet, this variable is either unseen or ignored.

PCT also explains how behavior can appear to be driven by cognitive processes such as planning and prediction, on occasions when it is not. For example, the simulated agents in object interception studies appear to predict where the ball will land because they are consistently in the right location at the right time (Marken, 2005; Shaffer, Marken, Dolgov, & Maynor, 2013). Yet, they manage this with no capacity to predict—only to maintain—perceptual variables, such as lateral velocity, at preselected values. There may indeed be a role for prediction when facing more sophisticated long-term problems, but this example illustrates that prediction is unlikely to be the fundamental property of the brain as popularly proposed (e.g., Hawkins & Blakeslee, 2007) or that it is necessary for many everyday tasks. The 'cognitive revolution' can be credited with placing goals inside the organism rather than on the outside. Yet, the cognitive revolution was incomplete because cognitive scientists still adhered to the view that these goals specified behavior (Marken, 2009). PCT models show that what we call behavior is a property of the organism and their environment that changes dynamically to control perception in a way that is not prespecified.

With the development of PCT, it has also become possible to explain why behavior changes not merely because it is maintaining a preselected state, but also because that preselected state can itself change. In Figure 1, the reference value $r(t)$ is set by the output of another control system that is located at a superordinate level in a hierarchy. This hierarchical organization is iterative, such that complex activities can involve multiple levels of control systems. Powers (1973) described in some detail the neural, physiological and anatomical components of such a hierarchy in humans. These are beyond the remit of the current article but they serve as a reminder that the epistemology of PCT is in fact recursive. We explained earlier how a strand of control theory emerged from homeostasis in biology. According to Carpenter (2004), Walter Cannon only paid a passing comment to hierarchies in his model of homeostatic systems. Yet PCT has informed more contemporary developments in the understanding of homeostasis (Carpenter, 2004).

Contemporary Directions

We have described the various origins of control theory in psychology, and described the essence of PCT, because it is fundamental to the development of contemporary self-regulation research. In addition to describing the functional organization of a closed loop, PCT also specifies how control systems are organized into hierarchical layers, and how learning occurs within these systems—a process known as *reorganization*. The versatility of this theoretical framework has been capitalized on by contemporary researchers, making it a dynamic, embodied, theory that is highly relevant today.

Research using PCT is changing the way that animal behavior is understood. It challenges the assumptions that stimuli are processed to trigger a response in a linear fashion and instead identifies control of perceptual variables as a principle that unites a diverse range of animal species. Sergio Pellis and Heather Bell conducted a program of studies at the University of Lethbridge, Canada involving coding the actions of animals as diverse as cockroaches, rats and crickets, to discover that their varied actions converge on the control of specific perceptual variables, such as the distance between individuals (Pellis & Bell, 2011).

The neuroscience of perceptual control is also burgeoning and questions the dominant view that the brain codes and plans its behavioral response. Henry Yin at Duke University, North Carolina has conducted a series of experiments to demonstrate how the basal ganglia of the brain do not control muscle actions directly, but rather they send signals downward to control a hierarchy of perceptual variables, such as change in position, through dynamic changes in muscle action (e.g., Barter, Li, Sukharnikova, Rossi, Bartholomew, & Yin, 2015).

Within sociology, Kent McClelland at Grinnell College, Iowa, uses PCT to model the social interactions of human groups in a way that is not possible using the alternative, descriptive theories within sociology. A recent study took the form of a computational architecture that was designed to test the hypotheses generated by a qualitative and descriptive model of social conflict escalation (McClelland, 2014). The model confirmed the hypotheses, and generated novel hypotheses of its own that fitted with naturalistic observations of conflict on social groups.

Finally, within the field of mental health, PCT has been used to develop a psychological therapy—known as Method of Levels—that is not specific to particular psychiatric disorders, that is, it is transdiagnostic (Carey, 2006; Mansell, Carey, & Tai, 2012). This method is designed to provide a more efficient intervention to train and disseminate that does not require a diagnostic assessment. Given the huge amount of resources directed toward psychiatric diagnosis and different treatment models for different psychiatric disorder, such an innovation has the potential to transform mental health practice. Open trials have shown large effects on reducing distress in a relatively small number of sessions (Carey, Tai, & Stiles, 2013) and shortening waiting lists (Carey & Spratt, 2009).

Summary and Conclusions

Control theory in psychology has many origins. Arguably, only one form of control theory—*perceptual control theory*—accepts that behavior itself is a process of control and explains how this process works—through the control of perceptual input. The theory has its origins around the same time as other control theory approaches that have gone on to inform man−machine models of psychology. These approaches, with the goal specification set outside the organism are inconsistent with the view of behavior as purposeful, yet they remain popular today within the human performance field. PCT, on the other hand, is beginning to influence psychology through the fields of social and clinical psychology. Yet, PCT is of the grand theory tradition, and can inform wider fields of psychology as well as the wider sphere of social and life sciences as demonstrated by its most recent applications. It remains to be discovered whether PCT will be regarded as the principal form of control theory in psychology going forward. This seems to depend on researchers' willingness to consider its premises and adopt its methodology. It depends on the purposes of psychological scientists in the future.

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