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Remodeling tradition in behavioral psychology: An empirical test of the control systems model as a theoretical and methodological alternative to conventional interpretations of person-environment relationships

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Indiana University of Pennsylvania, 1991

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REMODELING TRADITION IN BEHAVIORAL PSYCHOLOGY: AN EMPIRICAL TEST OF THE CONTROL SYSTEMS MODEL AS A THEORETICAL AND METHODOLOGICAL ALTERNATIVE TO CONVENTIONAL INTERPRETATIONS OF PERSON-ENVIRONMENT RELATIONSHIPS

A Dissertation
Submitted to the Graduate School
in Partial Fulfillment of the
Requirements for the Degree
Doctor of Psychology

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May 1991

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Title: Remodeling Tradition in Behavioral Psychology:
An Empirical Test of the Control Systems Model
as a Theoretical And Methodological Alternative
to Conventional Interpretations of
Person-Environment Relationships

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Because our assumptions about behavior guide the methods used to conduct and interpret research of behavioral phenomena, our conclusions may be misleading if our basic assumptions are incorrect. In this investigation a compensatory tracking task was utilized to examine subjects' performance data, both in terms of a conventional experimental paradigm based on Stimulus-Response Theory and that of an alternative paradigm and behavioral model, based on Control Systems Theory.

Three hypotheses were entertained: 1) that subjects are control systems for this task; 2) that the manipulations of feedback function and disturbance values would result in a statistically significant interaction between these variables on measures of subjects' handle position outputs; and 3) that a type of mathematical equation, relating input to output, would remain invariant regardless of these experimental manipulations and despite the occurrence of the expected observation in hypothesis two.

Analysis of the data supported all three predictions. Subjects continued to cancel variability in cursor position regardless of manipulations to feedback function. Despite the significant interaction of feedback function and disturbance values on measures of subjects' handle position values as revealed by the 2 x 3 within subjects ANOVA, person processes remained invariant, with changes in handle position always proportional to the area under the error curve. Findings of near zero variability in the proportionality factor (slopes), the lack of significant differences between slope-variance means, and nonsignificant differences in mean slope-means when the data were viewed in terms of the effects of changes in handle position on cursor position, further supported the hypothesis of invariance.

Discussion considers the ramifications of these findings with regard to current theories about how humans behave, and in terms of the methodologies with which we now attempt to investigate human behavior. Examined in particular is the meaningfulness of the conventional practice of inferring that something within the organism has changed based upon statistically significant findings.

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The dedication of this work and the accomplishment that it symbolizes truly belongs to those people who shared their love and belief in me with endearing conviction, and who bolstered my courage and healed my flagging spirits when I was ill.

My heart sings loudest to you Grandma, for your spirited lovingkindness and enduring faith in me always.

To Nan, a girl I know, and to Michael Wizer, for your inspiring friendship, and for always leaving the light on. To Gregg Dorris, Judi Rein and Gary Updyke for your open-hearted hugs and dissertation coans.

With fond reminiscence of another life with David McConaughey, who never once criticized me for making the choices I did, and also to John and Ila Mae McConaughey who kept me as their daughter.

To my sixth grade teacher Mrs. Grecian who first taught me that I was capable of anything I desired. To Russell Miars for your gentle direction in helping me find something that was too long misplaced. To Arne Freedman and Leon VandeCreek for the mentorship you provided. To Jay Mills for your unsurpassed supervision, and the opportunities you generated to really perform the art that I came here for.

To my mother and father, who best remember me as the kid that caused them all that aggravation, I am almost through.

May I last offer respectful remembrance to B.F. Skinner, whose theoretical position I oppose, but whose dogged opposition to persistent disturbances I greatly admired.

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CHAPTER I

INTRODUCTION

In the field of psychology, fundamental assumptions about behavior guide the methods traditionally employed to conduct and interpret research of behavioral phenomena. General accuracy about the basic assumptions underlying any model of human behavior must therefore be considered a prerequisite to conducting meaningful research in the study of human behavior. Clearly, if our basic assumptions are incorrect, our interpretive conclusions about human behavior based on statistically significant findings may be misleading. If we can isolate a circumstance in which a number of aspects of a person-environment transaction over time can be precisely monitored and very exact measurement of these various aspects recorded during different environmental manipulations, we might then see if the resulting data more closely fits our current beliefs and traditional interpretations about how people do this task based on Stimulus-Response Theory, or an alternative model, based on Control Systems Theory.

Control Systems Theory: Relevant History

Control systems theory posits that humans are negative-feedback control systems (Powers, 1973b). From this viewpoint, the individual is regarded to be a purposeful organism, one which is both capable of transformationally representing goals as signals within the perceptual system and of producing outputs which cancel out influences, or disturbances, that potentially interfere with those goals (Marken, 1990a).

As illustration, an individual driving down the highway, with the goal of observing the posted speed limit, might be described as controlling the variable of speed of travel. The speed limit of 55 miles per hour, is the reference value of that variable, represented as a signal, or more accurately a combination of signals, within the individual's perceptual system, from sensory receptors to cerebral cortex. Disturbances which cause or potentially cause deviations, or error, of the controlled variable from that reference value, would be effectively canceled by the individual's outputs. That is, disturbances to the vehicle's speed, such as those caused by inclines or wind, would be canceled by the driver's outputs in the form of muscle tensions which depress or release the accelerator.

Note that this person-environment interaction is described in terms of a negative feedback loop and also that certain ongoing processes within this loop occur simultaneously. Summarizing this interaction, both the influences of the driver's actions and conditions in the environment affect the speed of the vehicle; the combined effects of these influences are perceived by the driver; deviations of the perceived condition from the desired condition are computed; and outputs are produced so that the goal, or controlled variable, of travelling 55 miles per hour is continually maintained. More detailed discussion of control systems operation is described in subsequent sections and is illustrated in Figure 1.

In the field of psychology, the control systems perspective is by no means a new one. As early as 1896 Dewey, in his criticisms of the reflex arc concept, proposed a model of organism-environment transactions which contained the essential elements of a closed loop, negative feedback system. Ancestral fragments of control systems theory may also be easily identified in Wiener's (1948) principle of Cybernetics. Control systems concepts have also surfaced in human engineering psychology (e.g., Sinaiko, 1961) and in cognitive psychology (e.g. Ford & Ford, 1987). However, as a fundamental cornerstone in behavioral organization and person-environment transactions, the control systems perspective has received serious attention only by Ashby (1960) and Powers (1973b; Powers, Clark, & McFarland, 1960; Robertson & Powers, 1987). As we will see, this model, which focuses on a purposive organism interacting with its environment by way of its own physiological mechanism and through the process of negative feedback, contrasts sharply with the conventional stimulus-response (S-R) model of behavioral organization.

Stasis in the Field of Psychology and the S-R Model of Behavioral Organization

Since the 1950's the assumptions of an S-R model of behavioral organization in psychology have guided and defined experimental methodologies currently employed in investigating behavior. Behaviorism, one of the most influential movements in the history of psychology, describes behavior in the terms of stimulus and response (Watson, 1913; Broadbent, 1963).

Behavior, from the standpoint of this conventional viewpoint, is controlled by environmental stimuli, and the control function attributed to a stimulus is presumably acquired by association with reinforcing conditions. This notion of a stimulus-response cause and effect relationship both implicitly and explicitly describes behavior as a sequential, non-overlaping arrangement of discrete variables. From this perspective, stimuli, or cause/input, are presumed to be events occurring in the environment outside and independent of the organism. Behaviors emitted by the organism are described as response, effect, or output, and are presumed to be both precipitated and determined entirely by such external environmental events (Ferster & Perrett, 1968).

Historically speaking, the theoretical tenets of the cause and effect model in which the organism is viewed as respondent to environmental stimuli have largely influenced the developmental course of scientific methodology in psychology. Introduced as providing one of the first methods in which empirical studies of behavior could be conducted with objective measures, the model has been relied upon as a primary defense in defining psychology as a true science (Hergenhahn, 1986). This may in part explain why the theory has persisted, despite evident shortcomings, as will be discussed later, in adequately explaining behavior. This investigation offers an alternative model, one which regards people to be negative feedback control systems, that may better account for behavioral phenomena, Control Theory.

Basic Qualities of Negative Feedback Control Systems

By definition, negative feedback systems negate the influences of disturbances which would otherwise cause a controlled variable to fluctuate outside of designated boundaries (Powers, 1973b). Negative feedback devices such as the common household thermostat provide a crude analogy to the control system. The function of this device is to control a physical quantity, in this case air temperature, at some designated level (e.g. 68° F). Without the benefit of a control system, the physical quantity of temperature would otherwise vary as the result of disturbances acting upon it, such as heat loss through windows, or doors. To be effective, the control system must be able to sense the controlled quantity, it must be able to translate the controlled quantity into a detectable signal, and it must make comparisons of this signal with some condition that represent a goal or reference value. Discrepancies between the incoming signal and the reference value are considered error (Powers, 1973b).

To be effective, the control system must also produce outputs capable of cancelling the effects of disturbances that would otherwise lead to deviation, that is error, of the controlled quantity from this reference value. Note that to the observer the only observably apparent operation of the control system occurs at the level of output. As the control system continuously maintains the goal of 68° F, observable output does not always occur. For example when there is no effective disturbance that leads room temperature to depart from 68° F, the furnace does not turn on and off. During these periods of no output it would be incorrect to say that the thermostat was not operating to maintain room temperature.

Metaphors and Analogies

The operation of living control systems has often been described metaphorically as being much like the operation of servomechanisms such as described above (Bandura, 1978), and in much the same way that the computer has been used as a metaphor for processes of brain functioning. However, Powers (1973b, 1978) clearly expresses his objection to the suggestion that the notion of living control systems is modeled after servomechanisms. He argues that, to the contrary, it is precisely the reverse; servomechanisms are modeled after the human control system. Control devices, such as the thermostat, are therefore artificial control systems.

The function of a control system has also been linked to the notion of homeostatic process (Pavloski, 1989a). Where servomechanisms are oversimplified and mechanistic examples of control systems, homeostatic processes represent merely a subset of living control systems operation. While it is true that servomechanisms and homeostatic processes illustrate the notion of feedback which is central to control systems theory, they represent just one instance or type of the large range of behaviors explainable and encompassed by control theory. Far beyond metaphor, control systems theory offers a physically realizable model (Pavloski, 1989a).

Living Control Systems Operation

The operation of human control systems, as first introduced by Powers (1973b) and subsequently elaborated by Pavloski (1989a), may be described as follows and is depicted in Figure 1. Generally speaking, control systems arbitrate between environmental situations and internally-generated reference signals. This person-environment transaction of control systems involves two distinct operational relationships.

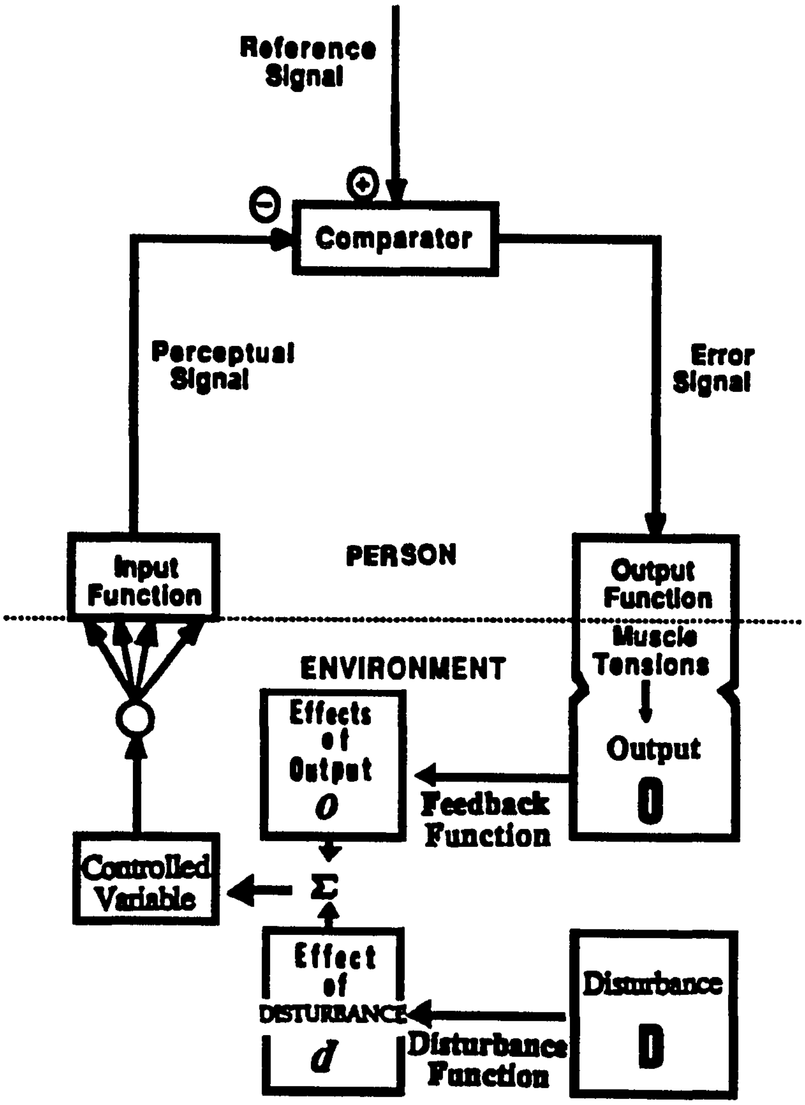

Figure 1. Living control system.

Person Contributions

Contributions of the person relationship in this transaction begin with the transformation of physical aspects of a controlled variable, as they impinge upon sensory receptors, into inputs which register within the organism as a perceptual signal. Perception, as it is used here, refers to an input signal generated at any level in the nervous system from sensory receptors to the cerebral cortex. Further, because a person may or may not report awareness for all levels of perception, Powers (1973b) argues that this process is not necessarily conscious. The transformation of aspects of a controlled condition into a signal is subject to the laws and principles of physics. As there are changes in sensory stimulation, the value of the perceptual signal varies.

Both the incoming perceptual signals and a reference signal are received by a comparator. The reference signal, which is generated inside the nervous system but from outside of the control system loop, is a perceptual representation that defines the desired state, or no error condition, of the variable being controlled (Powers, 1973a). Acting as a subtractor, the comparator computes ongoing differences between input and this reference signal. When these are equal, error is zero, when unequal, an error signal results. Error is then translated, via output functions and again according to physical laws, into outputs which are capable of influencing the controlled variable in a manner which eliminate this discrepancy. We can see from the diagram in Figure 1, that the impact of outputs upon the controlled variable, at any given time, is also an aspect of the perceptual signal. Our emphasis now switches to the relationship which represents environment contributions to this transaction.

Environment Contributions

Referring again to the control systems model in Figure 1, we can see that the controlled variable is influenced by two factors. These are described as the organism's output, here designated as **O**, and environmental disturbances, designated as **D**. For example, the position of a vehicle on the roadway is influenced both by our driver's volitional movements of the steering wheel and by environmental disturbances such as wind, variations in roadbed tilts or in road surface conditions.

Where the organism's output is described as **O**, the actual effects of this output upon the controlled variable are designated as **o**. For example, the effect of muscle tensions in turning the steering wheel, upon the vehicle's lane position, will depend partly upon the physical characteristics of the particular steering mechanism. This relationship is referred to as the feedback function, designated here as F. Similarly, where the value of the disturbance is described as **D**, the actual influence of this disturbance is designated as **d**. For example, the effect of a 30mph cross-wind upon the vehicle's lane position will depend partly upon the weight and aerodynamics of the vehicle. This relationship is the disturbance function, here indicated by G. We can see that it is the summation of the actual effects of disturbances, **d**, and organism outputs, **o**, which ultimately act upon the controlled variable.

As determined by factors, such as physical laws or fatigue, several variations of feedback and disturbance functions can occur as a control system operates. For example, feedback and disturbance functions may be linear, cubic, exponential, logarithmic, etc. Further, for any particular instance or task, the form of the feedback function and the form of the disturbance function need not be identical, but may exist in various combination. Returning to our driver, the relationship between degree of muscle tension exerted upon the steering mechanism to change tire angle 15° and road position could be exponential, while the relationship between the degree of cross-wind speed and road position is linear. The basic operation of the control system will remain the same, unaffected by the nature of the functions involved. That is, the effects of output will cancel those of the disturbance; road position will not change markedly from lane-center.

Several key points may be emphasized about each of these two processes of control systems functioning and their interaction. First of all, note that the selection of the controlled variable and its reference value are aspects of the person relationship, which implicit defines the control system as purposeful. In controlling this quantity of interest, the only access that the individual has about the effectiveness of their behaviors is by way of perceptual processes. Since all that we can ever know of our own behavior is obtained via our perceptions of the influences of that behavior on situations, Powers (1973a, 1973b) argues that individuals control what they sense not what they do. Therefore, from the control systems perspective, if it is true that individuals control not their outputs but their inputs or perceptions, "behaviors are simply the means by which we control these perceptions" (Vizza, 1989, p. 12).

Second, to the observer, overt behaviors are the only evidence of control systems functioning. However, these observable outputs, typically defined in scientific tradition as "behavior," will be apparent only when disturbances occur which influence this variable. From this perspective, the person responds not to a stimulus, per se, but to influences which interfere with the value of the controlled variable. When that variable is not being disturbed away from its controlled state by outside influences, there will be no discrepancy between the input signal and the reference signal, and therefore, no error signal. If there is no error signal, there is no "behavior" to observe. We can therefore say a person's outputs serve only as evidence that a disturbance has affected a controlled variable.

As a final point, we can see that at any given time the controlled variable is subject to both the effects of outside disturbances and the effects of the organism's output. It is the summation of the actual effects of disturbances, **d**, and organism outputs, **o**, which ultimately act upon the controlled variable. These effects, notably, do not occur sequentially, but simultaneously. Output is an integral aspect of input. The above mentioned relationships hold for controlled variables of any complexity.

To summarize, in control systems functioning the person may be seen as resisting effects which influence the perceptual signal and which would otherwise cause deviations between this signal and a reference signal to exceed a value of zero. To that end, the person is seen as intentional, or as carrying out a "purpose" or goal (Powers, 1973a, 1973b). By producing outputs which exactly cancel the effects of unpredictable and uncontrollable disturbances on a controlled variable, the control system continuously realizes a goal or purpose (Powers, 1973a, 1973b; Marken, 1980; Pavloski, 1989a). Because the individual continuously maintains a perceived aspect of a situation under constantly changing conditions, Powers (1973a, 1973b) describes control systems as goal-maintaining rather than goal seeking.

The ability to continuously realize a goal or purpose over time, despite the unpredictable and uncontrollable influences of disturbances to that purpose, is the outstanding feature of a control system (Pavloski, 1989a). An essential element for understanding the observed relationships between organism inputs and outputs concomitant with control system operation, is that of physical time. As implied above, the relationships depicted in Figure 1 are temporal relationships which are in effect all the time; they do not occur sequentially.

CST and the Physiological Organism

We are physiologically organized in a way that permits contact with the environment. Powers (1973b) presents the organization of a control system as hierarchical, conceptualized and arranged in a manner consistent with the physiological organization of the person.

As described by Powers, first-order control systems operate to control intensity of muscle tensions. Basic spinal reflexes describe the control systems loop at this level, which works to continuously maintain perceptual intensity signals at a value equal to the reference value of that system. When these do not match, outputs in the form of changes in muscle tensions are produced, eliminating the discrepancy.

First-order perceptual signals, when combined, become an aspect of second-order perceptual signals, and are received by second-order control systems as inputs via an interlinking arrangement of nerve fibers and synapses. Since these combined input signals carry information about intensity from many different sensory receptors, the second order system controls for a quantity, labeled by Powers, as sensation. These perceptual signals are then compared to the second-order system's reference value and any detected differences are transduced into outputs in the form of a reference signal to the first-order system. Any changes in reference value for the first-order system will lead to an initial increase in error signal for this system. This signal will then be transduced into outputs such that the incoming perceptual signal again continuously matches the changed reference signal value.

Powers (1973b) has postulated nine levels in the hierarchy of control systems operations. Control systems operation remains fundamentally the same across all nine of these levels. Differences between these levels exist primarily in terms of the nature of the quantity the system is controlling and its complexity. The hierarchy begins at the bottom with the least complex controlled quantity, intensity, upon which are arranged progressively higher ordered variables of sensation, configuration, transition, sequence, relationship, program, principle, and system concept. A very thorough examination of these variables, their experiential referents, and their hierarchical relationships is presented by Powers (1973b).

With the exception of the lowest level, where outputs are evident as overt behaviors in the environment, the outputs at each of the other levels of organization define the reference signal for the level below it. In that way, higher levels in the hierarchy may be seen as controlling their input since higher levels receive aspects of their inputs from these lower levels, which in turn operate to continuously match their own inputs to a reference signal, as defined by the higher levels and which may change over time.

Complexity of Controlled Variables

Controlled variables are represented in the nervous system through their transduction into a perceptual signal understood by the nervous system. Given the tremendous ability of the nervous system to perceive information about the environment, it is not unreasonable to hypothesize that the person can be a control system for a wide range of variables, regardless of complexity, as long as the organism has the necessary effectors to produce required outputs for opposing disturbances to this controlled quantity (Powers, 1973b). Humans therefore can control such complex variables as quality of driving performance, quality of work performance, and quality of a public speech.

As suggested by this range of complexity, a controlled variable may have unidimensional or multidimensional representations. Given a timed essay exam, for example, a student may be expected to monitor a number of dimensions relating to the controlled variable "quality of response", such as relevancy of information to the question, penmanship, and rate of production within the designated time allotment.

Comparative Analysis of S-R and CST Models

In the last few sections we have recounted the history and fundamental tenets of control theory, and have examined the basic principles of control system operations. We have also seen how the model is linked with the physiological organization of the individual. Let us see how this model contrasts with the conventional view of behavioral organization based upon S-R theory.

Closed Versus Open Loop Analysis and the Meaning of Feedback

Control systems theory would suggest that a central defect of the S-R model may be found in the failure to address the influence of feedback (Powers, 1973a). While it is widely agreed that feedback is an integral aspect of behavior, methodology based on the S-R model of behavioral organization reduces the ongoing process of behavioral phenomena to a unidirectional, and static arrangement of discrete events. That is, stimulus-response models arbitrarily translate what is generally agreed to be a closed loop system into an open loop system for analysis. The underlying presumption is that this string of sequences accurately represents the process from which it has been sampled. The validity of such a presumption has been repeatedly questioned historically (e.g. Wilden, 1980; Schwartz, 1983). At the level of description, stimulus-response models may be adequate statements of what the organism is observably doing; but at the level of process and explanation, the current model may reflect an oversimplification and even frank distortion of behavior. A closer look at stimulus-response theory illustrates how this might be true.

As stated, in the conventional model of human behavior, elements of behavior do not overlap, but are defined as discrete and fully independent of one another. Behaviors are regarded to be sequential and unidirectional events. Such a system is described as open loop.

While the simplicity of an open loop model is appealing from the viewpoint of conceptual ease of understanding, it overlooks the existence of feedback. Feedback effects are present in virtually all behavior (Powers, 1973a). As can be seen in the case of the driver in the scenario introduced earlier, elements of behavior are not independent, but overlap and mutually influence one another. Not only do environmental conditions have potential influences upon the driver, but the driver's outputs have an impact on environmental conditions, and so on.

The viewpoint that a person's behavior may be seen as a partial cause of that same behavior is not a novel one (Dewey, 1896). In fact, the existence of feedback in behavioral phenomena is a widely accepted notion and in some contexts, such as a tracking task, the explicit properties of feedback may be physically evident (Marken, 1980; Pavloski, 1989a). Systems of analysis which acknowledge and incorporate the influences of feedback are described as closed loop.

Within the behavioral tradition, the existence of feedback is not denied by S-R theorists, but mere acceptance of feedback, in principle, cannot not adequately compensate for its absence in the working model. In fact, such a model cannot "work" as the organism does, and therefore is not truly a model at all (Powers, 1973b). Closed loop and open loop models absolutely are not equivalent, nor are they interchangeable. As pointed out by Powers (1973a, 1973b, 1978), where feedback exists, the notion of conventional cause and effect relationships, as presented by S-R analysis, breaks down. This breakdown results because within the closed loop system, output becomes part of input. It is therefore incorrect to attempt to break this process into discrete sequences for analysis, as in doing so, the influences of feedback and physical time remain unaccounted for. Yet within the S-R tradition, it has been conventional practice to treat tasks involving feedback in this manner. By failing to explicitly account for the existence of feedback, its significant contribution to person-environment interactions is lost, and along with it, our ability to effectively explain behavior.

Trying to stretch the S-R paradigm

Early attempts to put the organism back into behavior have focused on acknowledging the existence of processes going on inside of the organism, such that the S-R paradigm became the S-O-R paradigm. It is not difficult to see that such incorporation, while perhaps marking a small victory for the organism, changes nothing about the basic arrangement of this model, which is forever, O-P-E-N L-O-O-P.

In acknowledgement of this difficulty, more recent theorists have attempted to incorporate feedback elements to address the transactional nature of behavior, (e.g. Lazarus & Folkman, 1984; Bandura, 1978). Bandura (1978), a significant S-O-R theorist, clearly promoted the view of bi-directional influences between the person, behavior, and the environment. Lazarus and Folkman (1984), in their treatise on stress, appraisal and coping, criticized antecedent-consequent models for their failure to recognize the mutual interplay of person and environment variables, and emphasized the need for research designs that accommodate this transactional and process orientation.

Upon closer examination however, these adjustments represent corrections made only at the level of theory, rather than at the level of method and analysis, and therefore have largely failed to have any meaningful impact upon the problem. Bandura distinctly argued for acknowledgement of feedback mechanisms present in behavior-person-environment interactions, but in the end he failed to explicate methodological procedures capable of studying this complex person-environment transaction. By replacing S-O-R with B-P-E (behavior, person, environment) and diagrammatically arranging the these factors into a triangle to acknowledge feedback, Bandura identified the problem, but may have failed to provide a viable solution by adhering, fundamentally, to stimulus-response theory as his premise. Lazarus and Folkman, while utilizing the correct terminology, have methodologically re-enacted S-R models by arbitrarily sequencing behavior for analysis. Thus, while using closed loop description, analysis remains open loop. Clearly the deeper meaning of feedback is overlooked.

Control theory argues that an accurate model of behavior must regard feedback as one of the causes of that same behavior. As Powers (1973a) states, "Quite literally [feedback] is behavior. We know nothing of our own behavior, but the feedback effects of our own outputs"

(p. 351). The accurate model must embody methods of analysis which does not ultimately contradict this principle. Control systems theory offers a model that embodies these concerns consistently in theory and method.

The separation between stimulus and response in S-R theory are arbitrary distinctions. They are convenient descriptive representations, but not really a factual accounting, of behavior, which unfolds over time and through the process of feedback. Output does not pause temporarily in order to wait for calculations of the effects of previous output upon the variable of interest to be computed before the next output occurs (Pavloski, 1989a). There is simultaneous influencing of output upon the controlled variable with that of disturbances upon the controlled variable, and physical time is necessarily required for these influences to occur.

Behavioral Reproduction and the Act Versus Result Distinction

Despite their subjection to influences not seen, controlled, or predictable by the person, behavioral events can be reliably reproduced. For example, Greg Louganis can execute a fairly consistent one and one-half gainer with a twist under a variety of conditions such as changes in board height or stiffness, weather conditions, muscle fatigue and footing. One can produce a constant result with variable acts (Powers, 1973a, 1973b).

Walking across the parking lot to a vehicle can be accomplished reliably on different days. This occurs even when initial conditions vary such as when the parking lot is icy, full of puddles, or unprotected from sudden strong wind. Observed in the act of walking to the vehicle on these different occasions, our pedestrian ultimately arrives at his car, but in the process, may take shorter steps on the icy day, detour around puddles on the rainy day, and lean forward and rest his hand on his hat on the windy day. Even when differences in initial conditions are not so drastic or apparent, reproduction of a behavior is rarely accomplished with identical actions. There must be continual adjustment of acts to achieve the same result. Variations in acts are necessary to keep the result the same; in absence of these variations, a constant final result would not occur (Pavloski, 1989a).

An important distinction between act and result is made by Powers (1973a). An act refers to how an organism performs a behavior, while a result is described as a consequence of that act. The historical focus in behavioral science has emphasized the result, or consequence, of behavior. Attention is directed to the "what" aspect of organism behavior. Clearly this focus cannot explain how the organism performs this behavior. Control systems theory may better account for the observation of consistency in a behavioral result with variability in behavioral response.

Conventional explanation dictates that variable acts are guided by cues which exist concomitant with each of the initial conditions. We may be quite susceptible to this S-R explanation for behavior particularly when a consequence is repeatedly produced even in the face of disturbances (Pavloski, 1989a). Powers (1973a) argues that a cue explanation is inadequate, in part because these cues are never actually "seen". All that can be seen is the behavioral result. Further, for a stimulus to effectively operate as a cue implies previous association with the cue. A cue explanation therefore does not account well for a constant behavioral result when initial conditions are novel.

Cause and Locus of Control

From within the stimulus-response tradition of Behaviorism, the behaviors of human organisms are controlled by stimuli in the environment. "A person does not act upon the world, the world acts upon him." (Skinner, 1971, p. 211). Yet this conclusion does not fit either intuition or the individual's self descriptions of their experience and behaviors in the world. One could reasonably expect that the majority of individuals would perceive themselves as planning, active, choiceful organisms, actively constructing the environment to conform to a plan, not as reactive and as determined by their past conditioning to environmental stimuli. In the past, the strongest argument against the traditional deterministic view has been based upon subjective report. However, despite Reid's famous assertion that "all of mankind could not be wrong and go against the wisdom of the ages" (cited in Lehrer & Beanblossom, 1975, p. 86), and as the historically significant debates about the nature of reality reminds us, science is not decided as a matter of popular vote. Fortunately, recent research data has been offered by control systems theorists which more convincingly challenges traditional thinking about purposeful organisms (e.g., Marken, 1980, 1982, 1983; Herzog, 1988; Pavloski, 1989a; Pavloski, et al., 1990).

Powers (1973b) concluded that whenever feedback exists, the cause for control must be regarded as an internal reference as opposed to a stimulus external to the individual. Marken (1980) nicely illustrated this point through the utilization of a cursor position task in which he asked subjects to keep a cursor aligned with a specified target. He observed that while subjects' performances on different trials were nearly identical in terms of response variations (as measured by handle position), the stimulus variations (as measured by cursor position) on each of these occasions were completely unrelated. Therefore, rather than responding to changes in external stimuli in order to stabilize these changes, the subjects were judged;, on the basis of the data and as consistent with the control systems perspective, to be responding to deviations from an internal reference.

For the control system, the regulation of some value of a controlled variable at a reference value may involve the production of acts by the person in order to cancel or minimize deviations, or error, from that reference value. Note that error, for our purposes, refers directly to deviations from a reference value; that is, an internal state of conditions within the perceptual system, and not to the external or environmental conditions, except by way of this representation. Where is the stimulus? It is in the person, defined as a potential or actual deviation, or error, of a controlled variable from a reference value. Thus, from this perspective, the individual controls for conditions in the environment that act upon a controlled variable(s) and not, as regarded from an S-R viewpoint, that conditions in the environment control the individual. The disturbance is outside the person; the cause for control however, a reference value in the perceptual system, is inside (Marken, 1980).

How Not What: Building a Better Rat

As argued above, control systems theory suggests that S-R models do not and cannot behave as the organism does. This is largely because the significant contributions of feedback and physical time in behavioral phenomena are overlooked by S-R models. As a result the model may be inadequate in providing explanations of the processes underlying behavior, such as those involved in the organism's ability to behave in novel situations or repeat the achievement of a behavioral result with variable acts. Further, S-R models also cannot reconcile the subjective experience that the human organism has of itself as being purposeful.

S-R analysis is a helpful descriptor of organism output. For example, when observing a rat in a cage, the S-R theorist can state that when a light comes on the rat runs over to the bar and presses it. This is useful information, that is, unless we wish to build a rat that will do the same thing. Control theory argues that S-R analysis is largely uninformative when we attempt to answer the question of how the rat operates.

Powers (1978) has pointed out that under conventional research paradigms, we often assume that the phenomenon under investigation is the meaningful observation, when in fact that phenomenon or event may merely be a side effect of control system operation. Powers labelled this the "objectification blunder." What the person is observed to be doing, may offer little meaningful data for explaining the person's behavior. While the crowd is focused on the touchdown pass, the quarterback is controlling for arm position, disturbances of wind and distance of his intended receiver on the direction and force of throw, and the disturbances of oncoming defensive players on his relative field position and rate of execution. While the additional six points on the scoreboard tell us what the quarterback did, it tells little of how the quarterback accomplished this. The data on the scoreboard are not helpful in producing the behavior that put it there.

The relevant question therefore is, not what, but how. Can we define the behavioral machinery in the organism that allows the organism to do what it does? Control systems theory offers a model that transacts with the environment, just as the person does. It is a model which behaves (Pavloski, 1989a).

Testability of Control Systems Theory

The hypothesis that humans are control systems is a testable one (Powers, 1973b; Powers, 1978; Pavloski, 1989a). If the outputs of a subject are highly correlated with disturbances applied to a hypothesized controlled variable and, if that controlled variable does not deviate significantly from a prescribed reference level despite these disturbances, we have evidence of the operation of a control system. One particular set of tasks which have proved useful in a number of research efforts investigating the control systems model are compensatory tracking tasks. Because of the explicit nature of feedback in compensatory tracking tasks (Marken, 1980; Pavloski, 1989a), they provide an ideal means by which to illuminate the basic framework of control systems theory and to test the relationships predicted by the theory.

Examination of S-R and CST Model Predictions on a Compensatory Tracking Task

Compensatory tracking tasks are perceptual motor tasks in which the subject is asked to control some specified condition, such as tracing a line with a cursor, on a video screen using a joystick. This variable, in addition to being influenced by the subject's outputs, is experimentally influenced by an unseen disturbance. In each of the control systems studies utilizing a tracking task, a number of relationships repeatedly emerge as a matter of course (Powers, 1978; Marken, 1980, 1982, 1983; Pavloski, 1989a; Herzog, 1988; Pavloski, et al.,1990; D'Agaro, 1990; Vizza, 1989). What are these relationships and how do they compare to the relationships we might expect to observe in such a task from the perspective of a S-R model of the subject's behavior?

Foremost, if subjects in compensatory tracking tasks are negative feedback control systems, then they should produce outputs which cancel the effects of disturbances upon a controlled variable. Observed variance therefore, is far less than the expected variance of a controlled variable, considering the presence of the disturbance (Powers, 1973a, 1978, 1979b). The data from several control systems studies utilizing tracking tasks demonstrate, unequivocally, such differences between observed and expected variance (Marken, 1983, 1986; Herzog, 1988; D'Agaro, 1990; Pavloski, et al., 1990). Figure 2 visually illustrates the variability of a cursor from center screen that we would expect when disturbances to that variable are unopposed. This is contrasted with the observed variability of this same variable, influenced by the same disturbance, when this influence is opposed by the subject as illustrated in Figure 3.

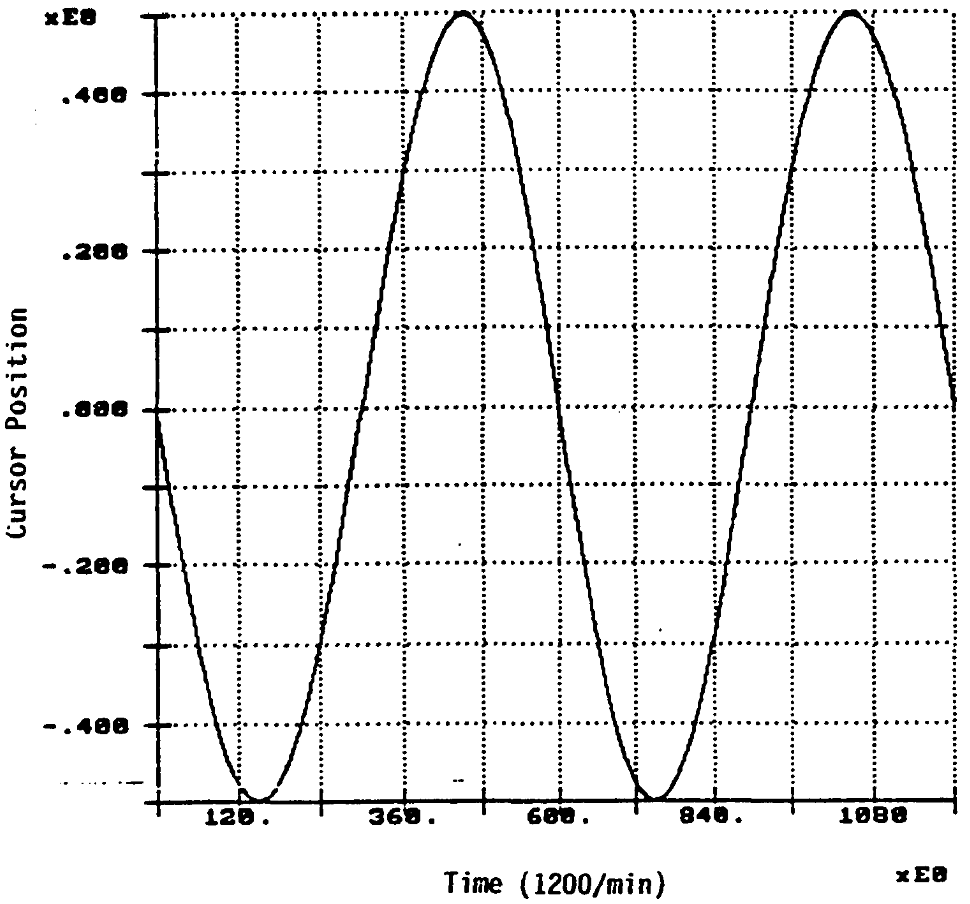

Figure 2. Cursor when unopposed (expected variability).

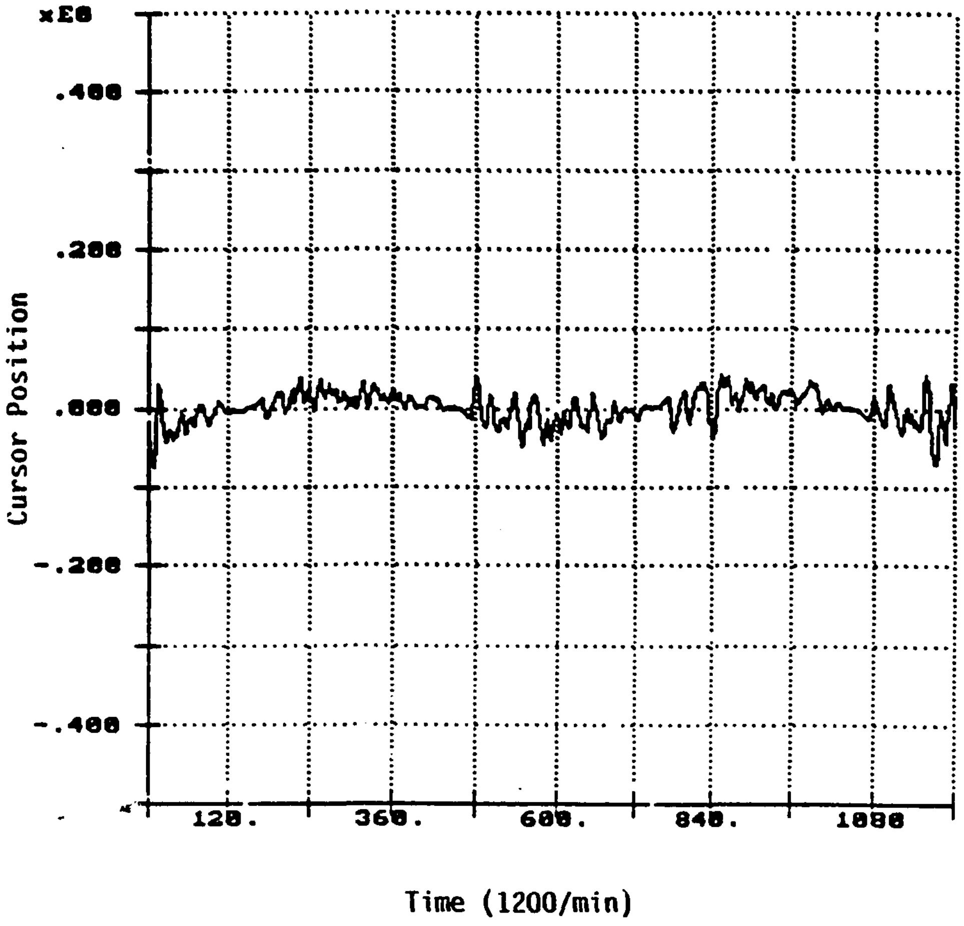

Figure 3. Cursor when opposed (observed variability).

Further, differences between expected and observed variance in tracking tasks appear to be quite robust even under conditions of challenge. Vizza (1989), manipulated levels of disturbance challenge in a cursor task and found that even the most difficult levels did not overwhelm control systems functioning.

In virtually all of the studies reviewed, subjects were explicitly requested to control a specific variable. Recall that since the nature, or selection, of a controlled variable is under the control of the person, such variables are generally not apparent to the casual observer. However, controlled quantities, while not evident to an observer, can be identified empirically (Powers, 1979a, 1979b). Marken (1983) hypothesized that if subjects were given a choice of two variables to control, he would be able, via continuous calculation of the ratio of expected to observed variance for each of two experimental variables, to correctly identify which of these potential controlled variables were in fact being controlled by the subject. His hypothesis was supported. His study suggests an avenue by which the identity of a controlled variable might be discovered in other situations.

Cursor position control tasks require a subject to keep a cursor positioned at a predetermined target location on a video screen. To compensate for disturbances to cursor position, the subject must vary the position of a joystick. How does a subject accomplish this? Sample data from past tracking task research studies which illustrate the typically observed relationships between cursor and handle position, and handle position and the disturbance are presented in Figures 4 and 5.

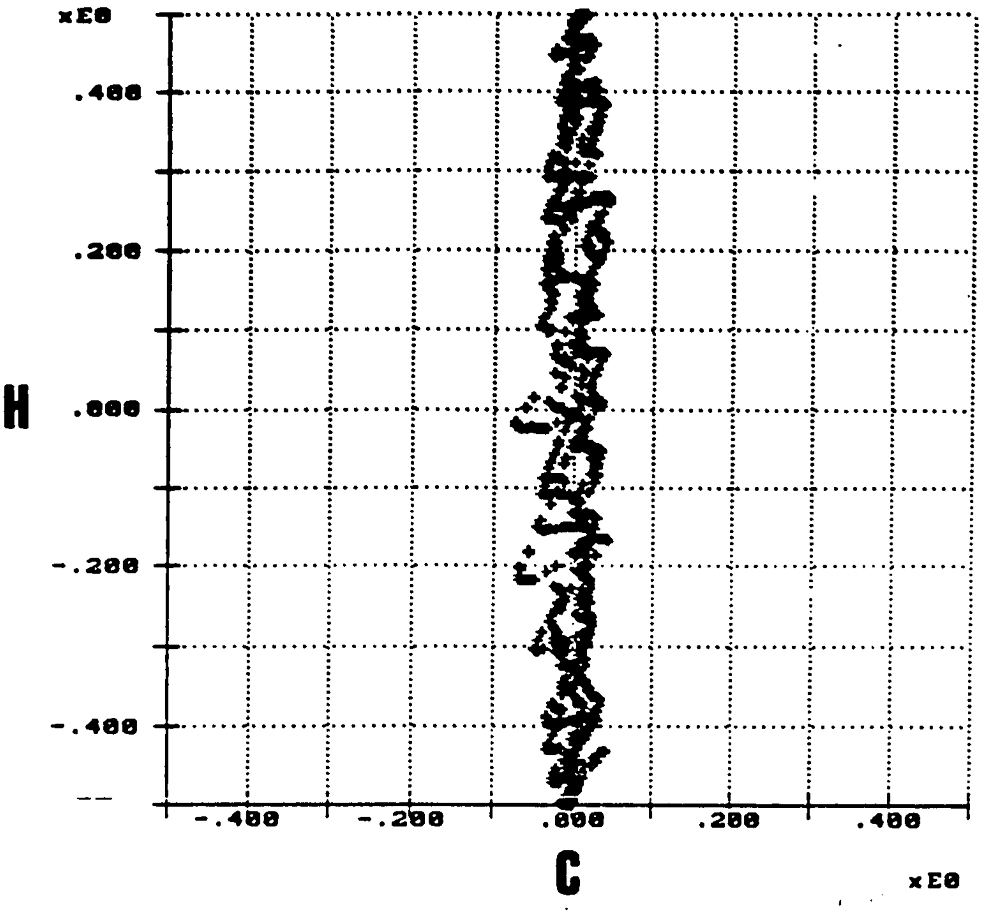

Figure 4. Scatter plot of handle position (H) and cursor position values.

From the viewpoint of a S-R model, observation of a subject in a tracking task would result in the conclusion that the changing position of the cursor acts as a stimulus (Pew, 1970, 1974; Wilde & Westcott, 1968), which leads a

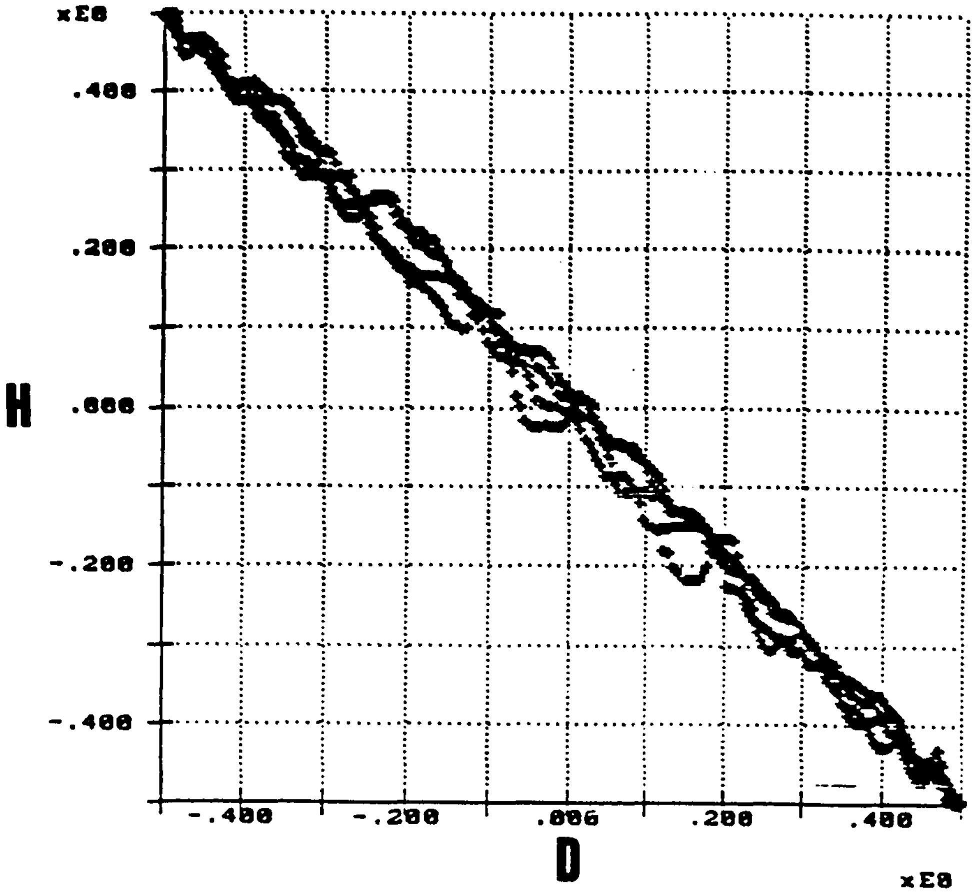

Figure 5. Scatter plot of handle position (H) and cursor position (C) values.

response emitted by the subject in the form of joystick movement in order to return the cursor to a predesignated position. While this theory appears to concur with first glance observation and intuition, we can see from Figure 4 that the expected S-R relationship does not emerge; cursor position does not at all predict handle position. In fact, Powers (19738) observed correlations between handle position and cursor position to be less than .1 in all instances.

The intuitive S-R prediction in this case is not observed because it neglects the fact that both the disturbance and the handle position of the joystick affect cursor position simultaneously. This existence of feedback from "response" to "stimulus", by definition, describes behavior as a closed loop process. That is, at any given moment, cursor position is both a cause and effect of the subject's behavior, and therefore cannot accurately be labeled as "stimulus" in the classical sense.

Still if behavior is organized to follow S-R laws, we should be able to identify some clear correlation between an environmental stimulus and subjects' behavior. Powers (1978) observed correlations between the handle position and the disturbance of greater than .99. This relationship is depicted in Figure 5, which certainly looks like an S-R relationship. However, this relationship may be regarded as quite remarkable from the S-R view, because the disturbance is not actually seen by the subject. True, it is partially revealed by its effect on the cursor, but we must remember that cursor position is also simultaneously being affected by the handle position. Again, output becomes part of input.

Additional observations further contradict an S-R explanation. If subjects' behavior follows S-R laws then the same disturbance should produce the same output. That is, using conventional terminology, an identical environmental stimulus should produce the same response. Logically then, there should be a high correlation between cursor positions on two nonconsecutive trials with an identical disturbance since this is the only stimulus available to the subject. Such a correlation is not observed (Marken, 1980), making S-R explanations unlikely, and adds the further complication that even with identical disturbances, the subject employs variable actions to achieve consistent behavioral results.

Further, Marken (1980) and Pavloski (1989a) have pointed out that the residual error, defined for example by deviations of the cursor from center screen, is random. Only as control decreases will there be a corresponding increase in the correlation between cursor values on nonconsecutive trials, due to the greater contribution of the disturbance on these variables.

Still, our casual observation of subjects in a compensatory task is quite compelling; we easily conclude that surely something that the subject perceives in the environment guides the subject's responses. If the cursor is not a stimulus, in the classical sense, perhaps subjects are relying on some sort of cognitive rule. For example, perhaps the person is just correcting for deviations of the cursor from the center line, such that for x number of units the cursor moves upward, the subject moves the handle a corresponding number of units downward. Yet as we have seen above and as depicted in Figure 4, experimental evidence does not support a top down or rule perspective. When performance data on a tracking task are plotted, there is little variability in cursor position, which does not markedly deviate from zero, while handle position takes on the full range of values. Attempting to modify the S-R paradigm by adding organismic variables, (S-O-R), does not appear to improve the ability of the model to explain the behavior of tracking task subjects.

While it may be no surprise that subjects keep a cursor at center screen when told to do so, we can see that only if we ignore the effects of feedback and physical time on cursor position does an S-R conceptualization of this behavior become plausible. Only if we arbitrarily fantasize that this system is made up of an arrangement of sequentially discrete events, that is open loop, can we create the existence of a stimulus that "causes" the person's behavior. The S-R model offers a description of the subject's observable behavior, but not an explanation of how the subject performs this behavior. We know intuitively and logically that the cursor is in some way linked to the person's behavior on the handle, but as we have also seen above, the person is doing more than just correcting for observable deviations of the cursor. How then does the subject control cursor position?

Recall from earlier discussion that the person-environment transaction of a control system is constituted of two process, the environment relationship and the person relationship. We have no direct access to processes within the person, however, this is not to say that we cannot build a hypothetical model of the person relationship. In fact, as Powers (1973a) first illustrated, we can represent each of the two interactive processes as mathematical equations and then empirically test the fit of these models to the behavior of subjects.

For example, as control theory posits, if cursor position at any given time, c(t), is determined jointly by the combined effects of the subject's outputs, **O**, and an unseen disturbance, **D**, then we can express the environment relationship as follows:

$$c(t) = F\,[\,O(t)\,] + G\,[\,D(t)\,] \qquad (1)$$

where F represents the feedback function, that is, the nature of the functional relationship between output and its actual effects on the controlled variable, and where G represents the disturbance function, or nature of the functional relationship between some disturbance and its actual effects on the controlled variable.

We can begin to extrapolate the processes of the person relationship by first examining a subject's hypothetical performance on a tracking task. Plotting cursor position as a function of time (as sampled every 1/20th s) produces a result similar to the diagram presented in Figure 6, where departures of cursor position from the specified reference value of center screen, or zero, fall above and below the horizontal axis. Any time that cursor position falls directly on this line, it matches the reference value, or no error condition. Bisecting this axis at instances where cursor position matches the no error condition and notating them as t_o, demarcates several segments in which cursor position can be described as a curve beginning at a point in which there is no error and ending at a similar point where again there is no error. We will call these segments, error curves.

We know, according to the control systems model, that any deviation of the cursor from the reference value of zero will be transduced into a perceptual signal that will eventually result in an error signal. In order to control inputs so that they again match a reference signal, we also know that the subject will transduce the error signal into outputs in terms of changes in handle position.

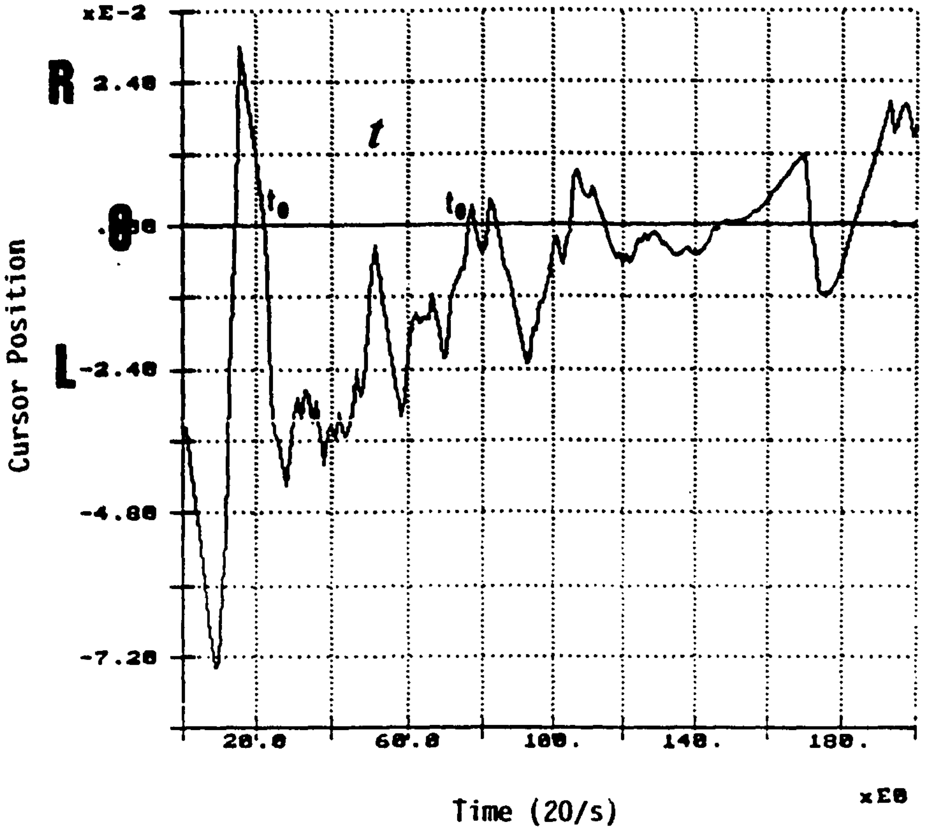

Figure 6. Cursor position as a function of time. Right sided (R) and left sided (L) errors are seen, respectively, above and below the no error position of center screen (0).

Using this information, we can mathematically express the person relationship as follows:

$$O(t) = O(t_o) + u \int_{t_o}^{t} e(t)dt \qquad (2a)$$

where the subject's output, or handle position at any given time, O(t), is equal to handle position the last time error was zero, $O(t_o)$, plus a constant parameter, **u**, times the area under the error curve, **e**, from the point we are measuring, **t**, to the last time error was zero, $\mathbf{t_o}$. The constant, **u**, is an individual differences variable which represents a specific individual's sensitivity to error.

We can alternately express Equation 2a as

$$O(t) - O(t_o) = u \int_{t}^{t} e(t)dt \qquad (2b)$$

which predicts that any changes in handle position, from the last time handle position was zero to the time we are measuring, are proportional to some constant times the under the error curve at the corresponding times.

Several investigators, by using similar mathematical equations to represent the person and environment processes of control systems operation, have devised simple control systems computer programs which have been able to simulate subject behavior on a variety of control system tasks with almost perfect correlation to subjects' motor skills performance (e.g., Marken, 1986; D'Agaro, 1990; Vizza, 1989; Pavloski, et al., 1990).

Advantages of Control Systems Theory

As argued in the sections above, there are several ways in which control systems theory may offer a more comprehensive and ecologically accurate model of behavior than existing models. Clearly, as we have seen, the differences between open and closed loop systems are not trivial. Where person-environment interactions have bi-directional causality, control theory can avoid the difficulty encountered by models which necessitate explicit identification of cause and effect as discrete and independent from one another (Powers, 1978). Additionally control systems theory also does not presume that cognition or emotion are the necessary cause of behavior.

Control systems theory not only offers an alternative explanation of behavioral organization, but it does so in a way which is consistent with the physiological organization of the person, and in a way which is consistent with humans' subjective experience of themselves as purposeful. Importantly, as we have seen above in the case of compensatory tracking tasks, the control systems model may be capable of better accounting for the data when investigating behavioral phenomena.

Scientific Resistance and Objections to Control Systems Theory

Initially, control systems theory did not gain the attention one might expect, given a clearly evident potential, as presented above, to advance understanding of behavioral phenomena. This earlier failure of control systems theory to attract serious attention as a reasonable alternative to the existing S-R model of behavioral organization may be attributable to a number of factors.

At a theoretical level, the most obvious and tempting criticism of control systems theory is that it is teleological, that is, that it proposes the idea that current behavior is being guided (or, in Behaviorist terms, "stimulated") by a future event such as a goal or intention. It is true, that a major tenet of control systems theory is that individuals are purposive and intentional (e.g. Powers, 1973a, 1973b; Marken, 1980, 1982, 1983, 1990a, 1990b; Robertson & Powers, 1987).

Furedy (1989) has argued that CST is teleological and therefore has no meaningful explanatory power. Based on this assumption, he further concluded that CST is not testable, as teleological explanations are circular. Neither of these conclusions are correct, as they are based upon outdated assumptions about what can actually be scientifically "observed" (Powers, 1973a, 1973b; Marken, 1982) and misinterpretation of the control systems model.

One common avenue to misunderstanding control theory occurs as the result of the absence of a language that can explicate the theory adequately. Without such a language it is difficult not to contaminate that explanation with meanings that may be automatically evoked by using commonly used terminology such as purpose, behavior, and stimulus. Criticisms based upon such misunderstandings have been clarified and refuted by Pavloski (1989b).

Another objection to control systems theory may be largely related to legitimate criticisms of the existing research that has been generated by control systems theorists. Although there is recent evidence of increasing activity, existing research is sparse. Early studies, aimed generally at basic demonstration of control systems operation, have often been conducted with very small sample sizes and have not necessarily followed accepted procedures for subject selection and assignment. Further, in a literature review of control systems theory research, replication studies were virtually nonexistent, although as we have reviewed, independent studies have nevertheless revealed repeat observations of the same underlying relationships predicted by the theory.

Despite early lack of attention, however, control systems theory has not been entirely ignored. Exploring the viewpoint that there is sequential maturation of increasingly complex levels of control systems, Plooij

(1984) has examined developmental data of humans and chimpanzees. Carver and Scheier (1981, 1982) have promoted the notion that control systems theory may be utilized in social, clinical and health psychology as a valuable "heuristic." Carrying this application a bit further, Hyland (1987) suggests that clinical symptoms of depression may be the result of prolonged control systems error. Significant error from a reference value has also been implicated as a mediator in cardio-vascular reactivity, a view which has also been preliminarily examined experimentally (Pavloski, 1989a; Herzog, 1988; Pavloski, Kennedy, Herzog and Arbitel, 1988). Finally, the recent publication of an issue of American Behavioral Scientist entirely dedicated to control theory ("Purposeful Behavior," 1990) suggests evidence that the credibility of control theory is growing and that interest is becoming more widespread.

Nevertheless, there is the remaining influence of a Zeitgeist that has strongly favored the S-R model, from which the fundamental underpinnings of sequential and open-loop analysis are now deeply rooted in our scientific methodology. Historically documented on numerous occasions throughout psychology's development, the resiliency of the Zeitgeist is often lasting and formidable even when quite viable alternatives are available (Boring, 1950).

An even larger obstacle to control systems theory may be the substantial metamorphosis required of the field of psychology at large in order to accommodate a model of behavioral organization which insists upon the existence of feedback. The consistent research findings of control systems studies cannot easily be incorporated into existing views or existing methodologies without seriously threatening the very premises upon which those views have been built. Thus, we must not only consider the effects of feedback on explanations of human behavior, we must consider the consequences of the pervasive presence of feedback on behavioral science. As stated by Powers, when we attend to the contributions of feedback to behavior, (1078) "Not only the cause-effect model breaks down, the very basis of experimental psychology breaks down as well." This is not to say that methodologies from a control systems theory are impossible to articulate, as the creativity of experimental designs in control systems theory by Marken (1980, 1982, 1983) and Pavloski (1989a, 1990) clearly attest.

It is true that open loop models of analysis offer ease of comprehension and execution in investigative research. The effects of a closed loop system are difficult to visualize; sequential open loop models offer a simplified description of organism-environment transactions. However, just as with language translations of important works, something gets lost. Often this something is essential to the true meaning of the work translated. We must remember that by simplifying behavior in this conventional manner in order to increase ease at making observations or studying behavior, what we consequently "observe" is an inaccurate reflection and representation of that behavior. To the extent that our major premise about behavior is in error, so will be any conclusions about behavior based on those premises. Analyzing behavior "as if" feedback does not exist in organism-environment transactions may lead only to faulty conclusions about this relationship. The existing methodology, based on an S-R model of behavioral organization indeed simplifies the operationalizing of behaviors and provides an unequivocal means to make distinctions between independent and dependent variables. Such distinction is prerequisite to statistical analysis of data. The difficulty here is that statistics do not prove our premise is correct. They assume our premise. They in effect say, if the premise is correct, an effect occurred within a designated level of probability. Beyond the fact that results are statistically significant, we have no real assurance that our interpretations of these results are ecologically accurate representations of how people actually behave.

Experimental Rationale

The intuitions that lead to easy acceptance of open loop analysis may perhaps be explained as largely a perceptual illusion in which the readily available cues are misleading. Overt behaviors easily command the attention of the observer, particularly when there are manifest changes in behavior. In the absence of easily available alternative explanations that seem more plausible, we are biased in choosing from the salient or immediately available. This tendency is not surprising, given current understanding of attribution, information processing, and cognitive biases. The capacity of such factors in leading observers to faulty conclusions is well documented (e.g., Arkes, 1981).

Reliance upon scientific method is a means of reducing our susceptibility to such forces and being led into the trap of accepting what only, on the surface, appears to be true. While it appears to be true, at first glance, that environmental stimuli cause behavior and that changes in stimulus-response relationships must reflect changes within the organism, this investigation hypothesizes that empirical evidence can easily show otherwise.

Challenging Tradition

Conventionally, in behavioral experiments, the investigator manipulates an element of the environment and observes the subject's consequent behavior. While we can, for purposes of rough comparison, use the control systems model as a map to trace this procedure in order to illustrate its possible weaknesses, the reader is reminded, however, that control systems theory proposes a model that is different in kind from S-R models. Any componential comparisons are therefore metaphorical and do not imply functional equivalence; to the contrary, they are offered as aids in gaining conceptual clarity about how cause-effect conclusions will inevitably be incorrect when the assumptions of S-R theory are employed as a methodology when investigating control systems phenomena.

Traditionally, when changes in behavior are observed subsequent to manipulations of environmental stimuli, it is assumed that these observed changes in stimulus-response relationships reveal some corresponding change taking place in the person. Inferences are then made about the meaning of the observed changes in stimulus-response relationships in terms of corresponding changes in person processes.

However, if people are control systems, and not simply input-output machines as the traditional model asserts, it may be that observation of changes in so-called stimulus and response relationships are relatively uninformative about processes within the person. That is to say, manipulations in the environment may reveal influences to a controlled variable in the environment, but not the person. A closer examination of the two general relationships within a control system, reminds us why.

Supporting the Challenge: One Model, Two Parts

Referring to earlier discussion and again to Figure 1, we are reminded that from the control systems view, the

process of organism-environment transaction contains two general relationships, one consisting of environment contributions to the transaction, the other consisting of person contributions to the transaction. The dashed line between the person-environment portions of the model reminds us that this is a somewhat arbitrary division; in actuality there is overlap because the model is closed loop.
Briefly restating, the environment relationship consists of the joint influences of organism output and outside disturbances upon a controlled variable. Recall that the organism's output is designated as **O**, and environmental disturbances are designated as **D**, whereas the actual effects of output upon the controlled variable are designated as **o**, and the actual effects of the disturbance upon the controlled variable are designated **d**.

We can see therefore, that it is not the organism's output and the disturbance directly that influence the controlled variable but their <u>effects</u>, as determined by the feedback and disturbance functions, which jointly influence the controlled variable. Stated differently, the same amount of muscle tension exerted on the steering wheel, or the same windspeed exerted on the car may have different eventual effects on the controlled variable at different times given that such things as the break-in period of the steering mechanism or variations in tire pressure change these relationships.

Recall also that the portion of the control systems model which represents the person relationship consists of perceptual representations which correspond to the ongoing state of a controlled variable, perceptual representations of the desired value of this condition, a comparator which computes differences between these two quantities and expresses them as error, and transformations of this error into muscle tensions aimed at cancelling any difference.

Salient properties of the person relationship relevant to this investigation may be summarized as follows. From the viewpoint of this model, note first that it is within the person relationship that the "cause" for the individual's behavior is contained via the person's choice of the nature and reference value of a controlled variable. It is not the case, from the control theory view, that situational aspects entirely separate from the person and which exist in the environment are the cause of behavior. Second, note that through this side of the relationship the person gains information about the effects of its own output and those of environmental variables by monitoring the ongoing state of the controlled variable via perceptual input. Finally, and most important, since these processes take place inside the person, we would not expect to have access to this side of the relationship, generally speaking.

What might be the significance of the person and environment relationships, as described above, to traditional experimental investigations and to inferences we make about the person? When investigators in a conventional study manipulate an environmental variable, they may indeed observe changes in the relationship between so-called stimuli and the subject's behaviors. For example, when investigators change the responsiveness of the steering mechanism or double wind speed, they are likely to observe changes in the effect of wind speed on the driver's overt behaviors. Conclusions are likely to be drawn that the person changed they were doing in response to the wind. But note how these inferences, are based entirely upon relationships occurring in the environment side of the transaction; in actuality we have evidenced nothing which assures us that anything at all has changed on the person side of this transaction.

In fact, as control systems theory indicates, and as this investigation hopes to explicitly demonstrate, the person has changed nothing about thay are doing; road position does not depart from center lane, despite the fact that we now observe that the driver steers with both hands instead of one. This investigation hypothesizes that how the person does this, _fundamentally_, is unchanged by the fact that what the person does _observably_, in order to accomplish this, has changed. In short, it may be that observers can say nothing meaningful about processes going on inside the person through direct comparisons of their outputs consequent to some variation in environmental condition in the conventional sense. Since outputs may simply occur as byproducts of the operating control system, all that can be said of variations in manifest behavior is that a variable that the organism is controlling has been disturbed and that an organism will oppose such disturbances through any number or variety of acts.

The Investigation

In this investigation a compensatory tracking task was utilized to test the experimental hypotheses. It was first necessary to establish whether or not subjects were control systems for this task by examining their performance data for the appearance of certain relationships between cursor position, output, and an unseen disturbance as predicted by the model. Given that these observations were present, thereby supporting the notion that subjects are indeed control systems for this task, we could proceed with the central hypothesis of this study which concerned the tradition of making inferences about changes in person processes based upon observation of changes in environment processes. Specifically, it was hypothesized that, as control systems, how subjects behaved in the cursor task would remain fundamentally the same, despite the observation of significant changes in the subjects' overt acts subsequent to experimental manipulations in aspects of the environment relationship of control systems operations.

The use of a cursor position task for this investigation was an ideal choice since, as has been noted in earlier discussion, all the essential elements of a control system could be operationally represented and observed. In this cursor position task, the horizontal position of a cursor projected on a video screen, was determined jointly by the control system's (subject's) manipulation of handle position and some unseen programmed influence, that is, by the person's output and environmental disturbances. Asking the subject to keep the cursor at center screen identified the controlled variable as "cursor position", and explicitly defined the reference value as equal to the center of the screen, which was assigned the value of zero.

The reader is reminded that, generally speaking, if humans are control systems, we would not expect that the identification of the controlled variable, nor its reference value, would be behaviorally apparent to the casual observer. This is because these particular elements, which represent the person's contribution to the person-environment transaction are, according to the control systems model, internal and their selection is under the control of the subject. Explicitly defining these for the subject permitted access to "observe" and measure these generally internal components. Further, since the current investigation was engaged at the level of demonstrating the operation of the control systems model and in making critical comparisons between this and traditional S-R models, rather than on testing its ability to explain behavior in specific circumstances, it was necessary to feel confident that the subject and the experimenter were focused on a constant and identical variable. This is the same kind of expectation we commonly make of subjects in conventional investigations. For example, in investigating the effects of different lighting elements on reading efficiency, we attempt to maximize conditions which assure the subject's best effort on the reading task so as to feel more certain that observed changes are related to the manipulation and not to changes in the subject's motivation to perform the requested task.

At this point in describing the tracking task, representation of all the essential elements of control systems operation except the disturbance function and the feedback function have been identified. Recall from earlier discussion, that there are many possible combinations of feedback functions and disturbance functions. This investigation employed the use of a computer to control environmental events. Disturbances were generated by a computer, utilizing a program and procedure devised by Pavloski (1989). The disturbance function for each of these random generations was defined linearly and remained unchanged for the entire experiment. That is, the program was arranged such that at any given time there would be a one to one correspondence between disturbance values, (**D**), and the effects of this disturbance, (**d**), upon cursor position values. While we might have used any form of relationship to experimentally define the disturbance function, a linear relationship was selected as a matter of convenience.

Experimental manipulations involved changes in feedback function. Depending upon the order of presentation, the feedback function was defined either in terms of a linear or nonlinear correspondence between the subject's outputs, (**O**), or handle position values, and their actual effects (**o**) on cursor position values. While we might easily have chosen to manipulate the disturbance function, manipulating the feedback function was judged to be better from a conceptual viewpoint. This manipulation may be described somewhat like changing the sensitivity of our driver's steering mechanism in the middle of the drive home; the same behavior now has a different effect on the vehicle's road position. Experimental manipulation of this functional relationship between the subject's output and it's influence on the controlled variable provided a context for focusing in on the relevant areas for critically evaluating control systems and stimulus-response models of behavioral organization, as well as their subsequent inferences about the subject's behavior.

The feedback function and the disturbance function as described above were expressed as mathematical equations which were then used, along with our knowledge of the control systems theory, to build a model which we hoped would allow us to reveal very predictable relationships in the subject's behavior for whatever values the feedback and disturbance function might take.

The mathematical representations of the relationships of interest are summarized as follows:

The disturbance function was defined as a linear relationship between **D**, the value of the disturbance, and **d**, the actual effects of that disturbance upon the controlled variable of cursor position such that,

$$\mathbf{d} = \mathbf{D} \tag{3}$$

which reflects a one to one correspondence between the disturbance value and its actual effects on cursor position values.

Depending upon the experimental condition, the feedback function was be either linear or nonlinear. In the first instance, feedback function was defined as a linear relationship between **O**, the value of the organism's output, and **o**, the actual effects of that output on the controlled variable of cursor position such that,

$$\mathbf{o} = \mathbf{O}. \tag{4}$$

Where the second case was true, the feedback function was defined as a nonlinear relationship between $\mathbf{O}$, the value of the organism's output, and $\mathbf{o}$, the actual effects of that output upon the controlled variable of cursor position such that,

$$\mathbf{o} = 2.5\ [\ \mathbf{O} - 1.23 \cdot \frac{\mathbf{O}^3}{|\ \mathbf{O}\ |}\ ] \tag{5}$$

and where $\mathbf{O}$ symbolizes the value of output.

Following the central tenet of control theory, it was predicted that if subjects in the experimental tracking task operate as control systems, then the influence of disturbances to the controlled variable would be canceled, almost exactly, by the influences of the subjects output upon the controlled variable. That is, we would expect that

$$\mathbf{o} \approx -\mathbf{d} \quad \text{therefore,} \tag{6}$$

it follows that for the condition in which both the disturbance function and the feedback function were linearly defined we would expect that,

$$\mathbf{O} \approx -\mathbf{D} \tag{7}$$

while for the condition in which the disturbance function was linear and the feedback function was defined as nonlinear we would expect that,

$$\mathbf{o} \approx -\mathbf{d} \qquad (8a)$$

Since,

$$\mathbf{o} = 2.5\ [\ \mathbf{O} - 1.23 \cdot \frac{\mathbf{O}^3}{|\mathbf{O}|}\ ]$$

then

$$\mathbf{o} = 2.5\ [\ \mathbf{O} - 1.23 \cdot \frac{\mathbf{O}^3}{|\mathbf{O}|}\ ] = -\mathbf{D} \qquad (8b)$$

Given that the above statements are true, we would expect the subject's output, in terms of handle position values to be predictable for any disturbance values entered into these equations. That is, experimental manipulation of feedback function were expected to produce very predictable relationships between the values of variables **O** and **D**.

The expected plot of subject output, in terms of handle position values, against disturbance values for the linear feedback function condition as defined in Equation 4, is depicted in Figure 7. The expected plot of subject output, in terms of handle position values, against the disturbance for the nonlinear feedback function condition as defined in Equation 5a, is depicted in Figure 8.

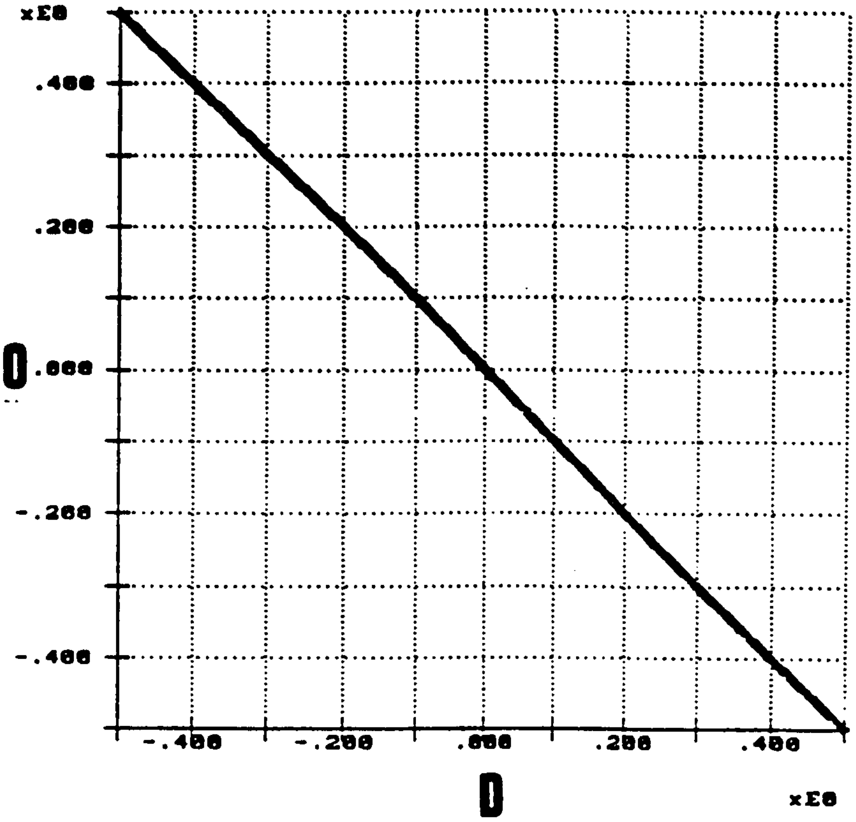

Figure 7. Plot of output values (O) against disturbance values (D) when feedback function is linear.

To facilitate the investigation, a computer was programmed to carry out the task of manipulating the nature of the correspondence between values of output (handle position values) and values of the controlled variable

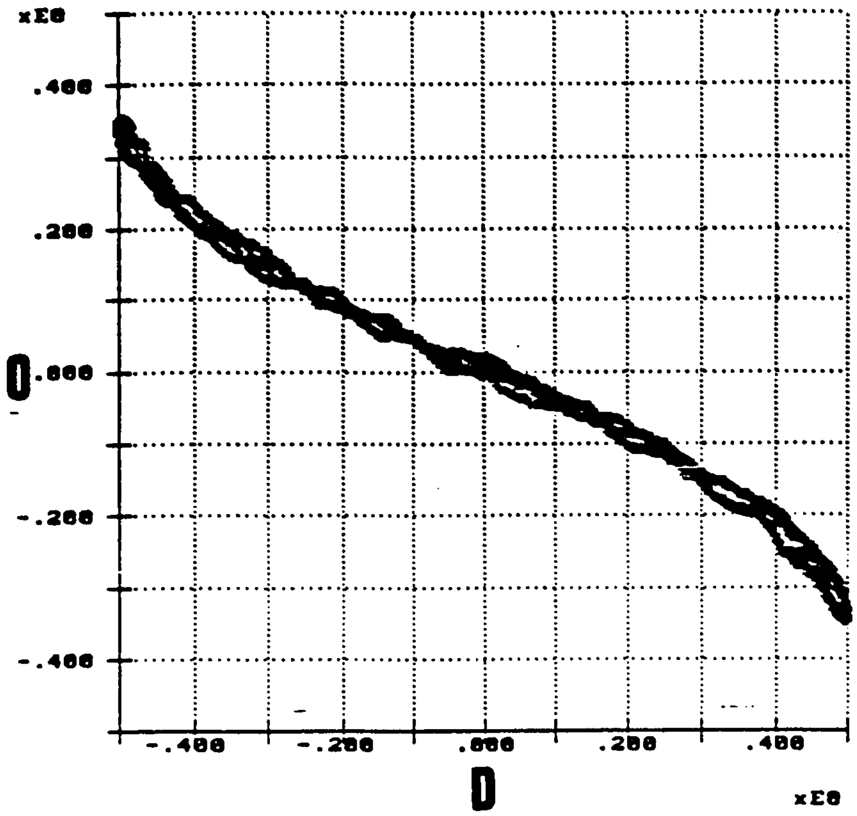

Figure 8. Plot of output values (O) against disturbance values (D) when feedback function is nonlinear.

(cursor position values) for the different feedback function conditions (i.e., linear or nonlinear), while maintaining a linear disturbance function across all practice and test trials. In this capacity the computer served as the subject's environment for the tracking task, since in control systems theory the feedback function and the disturbance are both regarded to be properties of the environment portion of the person-environment transaction and since they are the only influences which directly affect the controlled variable.

The critical interest was in monitoring the variability ot the person relationship in each of these conditions in which the environmental relationship is manipulated. The mathematical model of the person relationship as identified earlier in Equation 2b was employed for this task:

$$O(t) - O(t_o) = u \int_{t_o}^{t} e(t)dt$$

From this equation we would expect that changes in the subject's output (handle position), at any given time, are predicted by some parameter specific to the subject, times the area under the error curve at the corresponding times. If this person relationship were observed to be invariant across manipulations to the environment relationship, despite observable changes in subjects' behavior subsequent to these same environmental manipulations, this would provide evidence that these observable changes do not necessarily reflect any fundamental changes in what the subject is doing.

Specifically, it was predicted that for both of the experimental conditions, the position of cursor would always be proportional to the area under the curve, such that there would be a near perfect negative corrrespondance between the effects of the disturbance as defined in each of the experimental conditions and the handle (Figure 9).

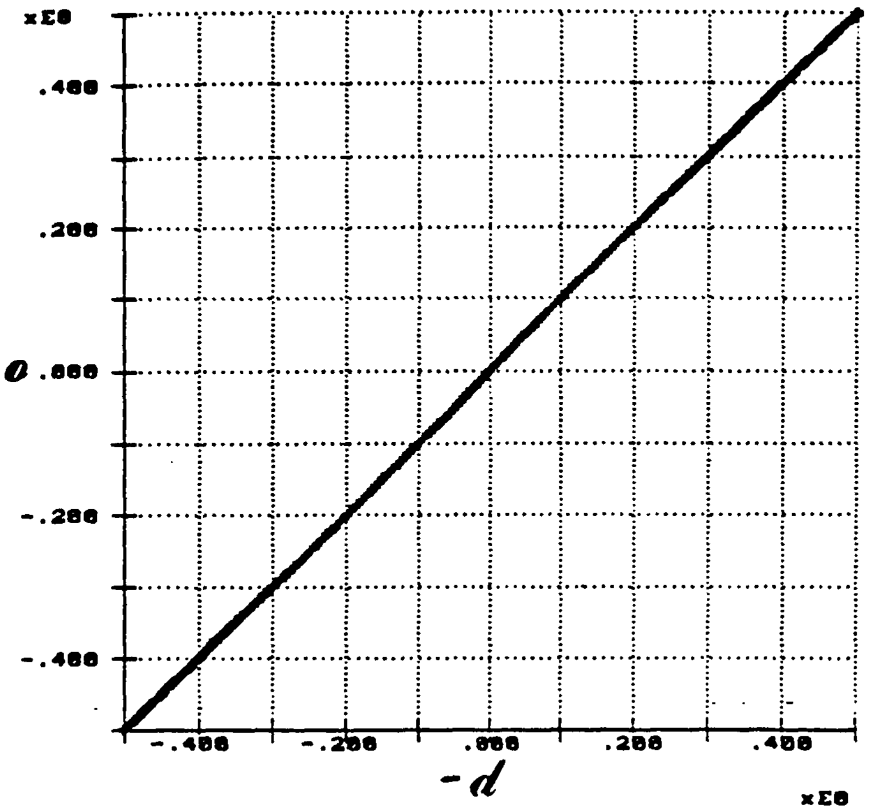

Figure 9. Expected plot of the effects of output, **o** , and the negative of the effects of the disturbance, **-d** , regardless of feedback function.

Summary of Rationale and Experimental Hypotheses

The central hypothesis of this investigation was based on a control theory model of behavioral organization and concerned the argument that observed changes in subject's behavior consequent to manipulations in the environment cannot be relied upon as reflecting changes within the subject. Testing this hypothesis first required that we establish that subjects were control systems for the experimental task. Second, it was necessary to observe significant changes in overt behavior corresponding to some environmental manipulation, such that the hypothesis of stability in the person relationship could be evaluated. The three hypotheses entertained in this investigation are summarized below.

Hypothesis #1: First, it was predicted that subjects would prove to be control systems for this task. If this is true, certain general observations would always be true, regardless of our experimental manipulation.

a. Foremost, subjects could be expected to oppose disturbances to a controlled variable (cursor position) such that these influences would be canceled and deviations from the reference value of that variable would not depart markedly from zero.

We therefore expected that the ratio of observed variance in cursor to the amount of expected variance in cursor position would be much less than 1.0, that is, o2 observed/o2 expected < 1.0. Restated, observed deviations of the cursor from the designated target were expected to be substantially less than the effects of an unopposed disturbance would predict. This observation would offer unequivocal evidence that cursor position is a controlled variable.

b. Second, it was predicted that handle position would be a function of the disturbance where again this function is a property of the environment. Thus, correlations between the effects of output and the negative effects of the disturbance were expected to approach +1.0.

Hypothesis #2. In the tradition of conventional behavioral research, this hypothesis considered the relationships between the subject's overt behavior (**O**, or handle position) and the disturbance (**D**) as they corresponded to manipulations of the feedback function.

It was predicted that manipulations of the feedback function, a property of the environment, would lead to subsequent changes in observations of the relationship between the subject's overt behavior (**O**, that is, handle position) and the disturbance (**D**) between conditions, and that these changes would reveal a highly significant statistical interaction.

Hypothesis # 3. Most important, it was predicted that as feedback function changed, a property of the environment, the person function would remain the same.

Changes in handle position were expected to remain proportional to the area under the error curve regardless of experimental manipulation of feedback function.

CHAPTER II

METHOD

Subjects

Subjects participating in this study consisted of 10 male and 10 female volunteers from the student population at the Indiana University of Pennsylvania. Subjects were contacted at least 24 hours prior to the experiment and were requested to abstain from using any drug for at least five hours prior to the experiment to insure against performance impairment. Five males and five females were randomly assigned to the counterbalanced treatment conditions outlined below. Because of the small expected within groups variance, it was anticipated that this number of subjects would be adequate.

Apparatus

An IBM-AT compatible computer fitted with an Enhanced Graphics Adapter and a Metrabyte DAS8 analog-digital converter board was utilized to carry out the pre-programmed experimental manipulations during each trial, to collect performance data for these trials, and to carry out subsequent preliminary analysis of the data. A 10Kohm potentiometer with 56° of arc, manipulated manually by a handle, was employed as a joystick for maneuvering cursor position on the display screen.

Experimental Manipulation

The experimental tracking task consisted of two sets of practice and test trials. Disturbances were generated by the computer. For all practice and test trials the disturbance function was linearly defined. For each of the two sets of test and practice trials the feedback function was either linear or nonlinear. All subjects received both sets of practice and test trials, the order of which was counterbalanced.

The identity of the controlled variable and its reference value, were explicitly and experimentally defined as follows. The horizontal position of the cursor on the video screen, determined jointly by the influences of handle position and a random disturbance, was able to vary from -.5 to +.5, an arbitrarily chosen range of values. Cursor position, when aligned with a target symbol located in a fixed position at the center of the screen (Figure 10), takes on the value of zero. Asking the subject to keep the cursor aligned with the target at center screen, defined the controlled variable as "cursor position", and explicitly defined the reference value as equal to zero. Therefore, any movement of the cursor to the left or the right of center screen position was considered error. Cursor position, at the beginning of any trial, was always center screen, zero. During all trials, cursor position, stick

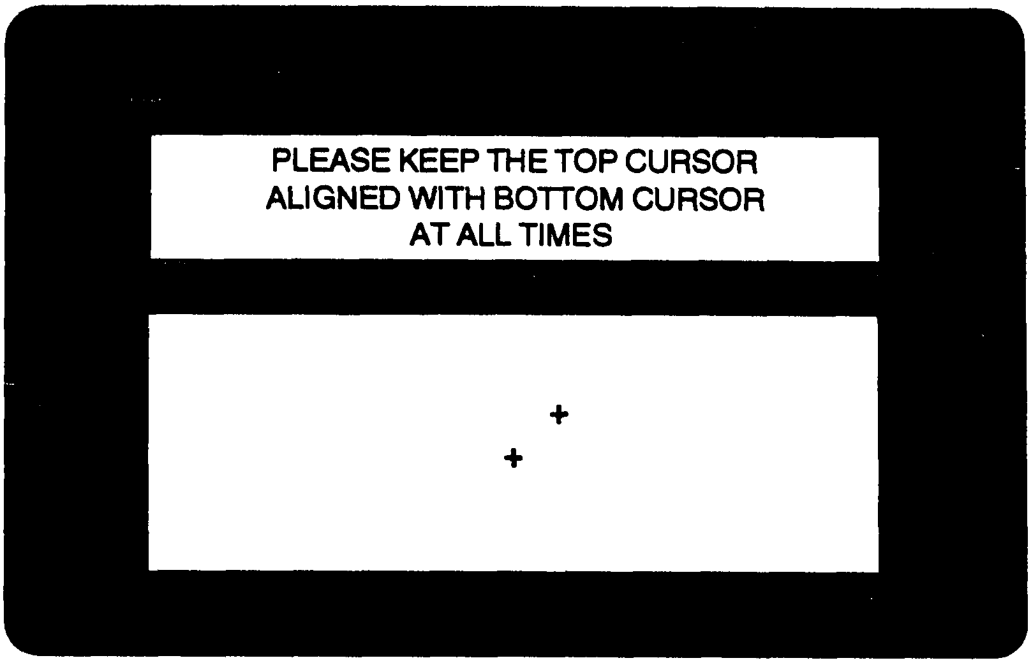

Figure 10. Cursor task video display.

position, and the disturbance were sampled via an analog-to-digital converter at the rate of 20 times per second, for a total of 1200 data points per minute of performance.

Procedure

Just prior to their participation in the study, subjects read and signed an informed consent form. Experimental sessions were conducted in an 8 by 10 ft (2.5 x 3.0 m) temperature-controlled, and sound-insulated research cubicle. To further minimize outside distractions that might interfere with task performance, headphones broadcasting white noise were worn by each subject.

The tracking task was visually presented on a video screen. Subjects sat in a chair approximately 3 ft (1 m) from the viewing screen. A computer joystick, calibrated prior to each experimental session, was placed to the subject's right or left depending upon hand dominance. Prior to presentation of the task, subjects received a brief introduction to the study, with task directions also visually displayed on the video screen. Just prior to each trial presentation subjects were visually reminded, "Please keep the top cursor aligned above the bottom cursor." Each subject then began practice trials of 1 min each for a minimum of 3 practice trials, until an asymptotic criterion was met. This criterion was designated operationally as 98% reduction of the variance in cursor position on a single trial. Subjects unable to reach criterion by the 10th practice trial could be reasonably judged not to be controlling cursor position and therefore, consistent with methodologies in traditional learning paradigm studies, would be dismissed from the study. There was a 15 s pause between all trials. Prior to introduction of a new trial, the cursor position returned to center screen. Immediately after the subject completed a set of practice trials that satisfied the asymptotic criterion, the series of five test trials began. Other than informing the subject of whether or not they had met the criterion, no additional instruction was given prior to presentation of the test trials. After completing the first set of practice trials and test trial with one feedback function, the procedure was repeated with the second feedback function. In the informed consent form and prior to task presentation, subject's were encouraged to make their best effort in controlling cursor position. During the presentation, the experimenter remained in the room but out of the subjects' line of sight. The time required for each subject to complete the study was approximately 40 minutes.

CHAPTER III

RESULTS

Hypothesis One: Manipulation Check

The testing of hypotheses two and three was conditionally dependent upon the observation that subjects are control systems for the experimental task, the prediction presented in hypothesis one. The choice of a compensatory tracking task provided the necessary conditions to unequivocally evaluate this prediction, since control theory asserts that a control system will oppose disturbances to a controlled variable, here defined as cursor position. The requirement that subjects reach a predetermined asymptotic criterion for participation in the study, in addition to providing some reassurance that subjects were motivated to consistently control the same variable that the experimenter was interested in, leads to the observation of the predicted relationship for hypothesis 1a, and therefore serves as a manipulation check. The asymptotic criterion in this study required that subjects reduce 99% of the expected variance in cursor position, that is, the observation of 99% reduction of the expected effects of an unopposed disturbance upon cursor position in terms of deviations from the designated target.

To evaluate hypothesis 1a, calculation of the percentage of cancellation of variance in cursor position was conducted on a trial by trial basis, utilizing the 1200 values for the expected range of the disturbance as compared to the corresponding 1200 values that cursor position actually took during each 1-min trial (Table 1a). In both conditions, and regardless of order of presentation, all subjects were able to meet the criterion of a minimum of 99.0% cancellation of variance in cursor position without attrition. In the interest of achieving a stable baseline performance, the study also required that subjects receive a minimum of three practice trials prior to presentation of the test trials; however, it is worthy to note that 12 subjects reached criterion on their first practice trial in both of the conditions, the remaining 8 subjects did so in one condition only, and only 2 subjects required greater than three practice trials in either condition (four and five practice trials, respectively) to meet and remain at the asymptotic criterion before receiving test trials. The lowest percentage of cancellation of variance observed in any single practice trial which failed to meet criterion was 95.8%.

During presentation of the five test trials in each condition, all subjects, with rare exception, continued to maintain the minimum of 99.0 %, and frequently exceeded 99.8% cancellation of variance in cursor position (Tables 1b and 1c). Only five subjects produced <u>any</u> test trial below the criterion of 99.0%, in which case the lowest observed cancellation of variance in cursor position was 98.1%.

Table 1a

Percentage of variance of cursor position canceled by subject output during practice trials.

	Trials								
Sub.	Linear					Nonlinear			
	1	2	3	4	5	1	2	3	4
1	98.0	99.0	99.3			99.3	99.3	99.2	
2	98.1	99.3	99.2			99.4	99.3	99.5	
3	98.1	98.7	99.0			99.3	99.4	99.3	
4	98.9	99.0	98.6	99.1		99.3	99.6	99.0	
5	99.5	99.6	99.7			99.6	99.6	99.6	
6	99.2	99.5	99.6			99.7	99.6	99.5	
7	99.7	99.8	99.8			99.8	99.8	99.7	
8	99.4	99.6	99.8			99.8	99.7	99.7	
9	99.2	99.4	99.3			99.6	99.7	99.6	
10	98.7	99.2	99.3			99.5	99.6	99.5	
11	99.4	99.1	98.5	98.7	99.2	96.7	97.9	98.7	99.1
12	99.4	99.5	99.5			99.1	99.3	99.6	
13	99.7	99.8	99.7			99.6	99.7	99.7	
14	99.6	99.4	99.7			98.4	99.1	99.2	
15	99.5	99.1	99.6			98.6	98.9	99.4	
16	99.1	99.1	99.0			95.8	99.1	99.1	
17	99.7	99.7	99.7			99.3	99.2	99.4	
18	99.8	99.8	99.8			99.3	99.4	99.4	
19	99.4	99.8	99.8			99.5	99.6	99.6	
20	99.7	99.6	99.8			99.8	99.3	99.5	

Table 1b

Percentage of variance of cursor position canceled by subject output during linear test trials.

Subject	Linear Test Trials				
	1	2	3	4	5
1	99.4	99.5	99.3	99.4	99.5
2	99.4	99.5	99.3	99.4	99.4
3	99.1	99.0	98.7	99.0	99.2
4	99.0	99.3	99.4	99.5	99.4
5	99.7	99.7	99.5	99.5	99.4
6	99.6	99.7	99.7	99.7	99.7
7	99.8	99.8	99.8	99.8	99.8
8	99.8	99.7	99.8	99.7	99.7
9	99.5	99.4	99.5	99.6	99.3
10	99.6	99.6	99.4	99.5	99.7
11	99.5	99.5	99.4	99.5	99.6
12	99.5	99.4	99.5	99.5	99.6
13	99.7	99.5	99.6	99.6	99.7
14	99.7	99.6	99.7	99.6	99.7
15	99.3	99.6	99.5	99.4	99.3
16	99.5	99.6	99.5	99.5	99.5
17	99.7	99.7	99.7	99.8	99.7
18	99.8	99.9	99.9	99.8	99.7
19	99.7	99.8	99.7	99.7	99.7
20	99.8	99.7	99.7	99.7	99.7

Table 1c

Percentage of variance of cursor position canceled by subject output during nonlinear trials.

Subject	Nonlinear Test Trials							
	1	2	3	4	5	6	7	8
1	98.1	99.6	99.2	99.4	99.2	99.5		
2	99.5	99.5	99.4	99.5	99.5			
3	99.3	99.1	99.4	99.4	99.1			
4	99.6	99.4	99.5	99.3	99.6			
5	99.6	99.8	99.7	99.4	99.7			
6	99.7	99.7	99.7	99.6	99.6			
7	99.8	99.8	99.7	99.8	99.8			
8	99.8	99.8	99.7	99.7	99.8			
9	99.6	99.5	99.5	99.5	99.4			
10	99.5	99.5	99.6	99.7	99.7			
11	99.2	99.0	99.2	98.9	99.3	99.2		
12	99.4	99.5	99.5	99.6	99.5			
13	99.7	99.7	99.7	99.7	99.6			
14	99.4	99.4	99.4	99.5	99.6			
15	99.4	98.8	98.5	99.2	99.3	98.9	99.3	99.5
16	98.8	99.2	99.1	99.2	99.2	99.3		
17	99.4	99.6	99.6	99.7	99.4			
18	99.8	99.8	99.7	99.7	99.8			
19	99.7	99.7	99.8	99.7	99.6			
20	99.6	99.8	99.6	99.7	99.7			

These observations strongly support hypothesis 1a.

Hypothesis 1b predicted that output (handle position) is a function of the disturbance. This prediction follows from an understanding of control theory which posits that the output of a control system serves to cancel influences upon a controlled variable. Thus, if subjects are indeed control systems for this task, canceling disturbances to a controlled variable via output, we would always expect there to be a near perfect negative correlation between the effects of our subjects' output (**o**), in terms of handle position and the effects of an unseen disturbance (**d**). The prediction of this relationship was evaluated by examining the Pearson product moment correlation coefficients between the effects of handle position on cursor position and the negative effects of the disturbance on cursor position, r (**o**, -**d**), as sampled 1200 times per minute for each of the subject's five test trials in the two feedback function conditions. Consistent with the hypothesis, and as can be seen by the subject's final sample test trial data for the different feedback function conditions in Table 2, these correlations always exceeded +.99.

Hypothesis Two: Evironment Function

The prediction of a significant interaction between feedback function and the disturbance (**D**) as a determinant of output (**O**), was examined via a 2 x 3 within-subjects ANOVA, with Feedback Function and Disturbance Values serving as independent variables. The two levels of the Feedback Function variable were defined as linear and nonlinear. The

Table 2

Correlations between handle position (output) and disturbance for the final test trial in both linear and nonlinear feedback function conditions.

Linear		Nonlinear	
Subject	Correlation	Subject	Correlation
1	.9966	1	.9964
2	.9965	2	.9967
3	.9944	3	.9947
4	.9962	4	.9972
5	.9964	5	.9979
6	.9979	6	.9975
7	.9984	7	.9985
8	.9980	8	.9984
9	.9960	9	.9966
10	.9975	10	.9979
11	.9971	11	.9952
12	.9974	12	.9969
13	.9980	13	.9972
14	.9978	14	.9971
15	.9958	15	.9967
16	.9964	16	.9960
17	.9981	17	.9961
18	.9980	18	.9981
19	.9980	19	.9972
20	.9980	20	.9980

three levels of the Disturbance Values variable were identified as -.25, .00, and +.25, as defined by the central and mid-range values taken by the computer-generated disturbance during any 1-min. trial.

For each occasion when the disturbance was at one of the above designated values, the corresponding handle position (output) produced by the subject was computed. Each subject's mean handle position for each of the three disturbance values was subsequently calculated across the five test trials and in each feedback condition for use as a dependent variable (Table 3). Since each disturbance consisted of a 2 cy/min sine wave, the designated disturbance values of -.25 and +.25 were expected to occur only twice each for each 1-min test trial (as opposed to five times for the disturbance value of .00); therefore it was decided that sampling would include all occasions when disturbance values were at these designated values +/-.05, providing greater assurance of a good estimate of the mean handle position values.

The analysis of interest was the examination of the interaction between Feedback Function and Disturbance Values, however, in order to rule out the possibility of influences due to order of presentation or subject sex, the initial analysis involved a 2 x 2 x 2 x 3 mixed-plot ANOVA.

Table 3

Mean handle positions corresponding to designated disturbance values for each of the feedback function conditions.

Subject	Linear			Nonlinear		
	Disturbance Value					
	-.25	.00	.25	-.25	.00	.25
1	.2488	.0051	-.2469	.1201	.0010	-.1208
2	.2502	-.0030	-.2438	.1178	.0012	-.1200
3	.2502	-.0006	-.2546	.1168	-.0031	-.1201
4	.2529	.0042	-.2420	.1176	.0024	-.1134
5	.2502	-.0001	-.2495	.1164	.0015	-.1102
6	.2592	-.0021	-.2495	.1156	.0013	-.1158
7	.2512	.0011	-.2496	.1125	-.0012	-.1137
8	.2486	-.0041	-.2499	.1166	-.0035	-.1158
9	.2428	.0019	-.2442	.1187	-.0005	-.1152
10	.2546	.0065	-.2447	.1242	.0045	-.1134
11	.2529	.0035	-.2404	.1220	.0022	-.1149
12	.2539	.0052	-.2553	.1161	.0011	-.1174
13	.2490	-.0003	-.2529	.1162	-.0027	-.1160
14	.2537	.0012	-.2462	.1181	.0040	-.1122
15	.2559	-.0053	-.2432	.1198	-.0016	-.1145
16	.2503	.0040	-.2463	.1169	.0053	-.1137
17	.2589	-.0026	-.2470	.1196	-.0006	-.1093
18	.2517	.0050	-.2488	.1188	-.0024	-.1157
19	.2527	.0014	-.2469	.1163	.0019	-.1112
20	.2539	.0009	-.2515	.1209	.0002	-.1120

This analysis revealed a nonsignificant effect for both Order, F(1, 16) = 1.09, p > .31, and Sex, F(1, 16) = .33, p > .57, permitting collapse across these variables. As expected, the subsequent 2 X 3 within-subjects ANOVA revealed a highly significant interaction, Rao R, Form 2(2, 18) = 12793.8, p < .000005. Table 4 contains a summary of the univariate analysis, with cell means presented in Table 5. The interaction effect is illustrated in Figure 11.

Table 4

Analysis of variance of handle position values for feedback function and disturbance values.

Analysis of Variance					
Source	df	Sum of Squares	Mean Squares	F	p
SS	19				
Feedback Function (FF)	1	.000012	.000012	3.080	.09
Error	19	.00071	.0000037		
Disturbance Value (DV)	2	2.68190	1.34095	140,000.	.000005
Error	38	.00037	.0000097		
FF X DV	2	.35576	.17788	17,367	.000005
Error	38	.00039	.00001		

Table 5

Mean handle position values as a function of Feedback Function and Disturbance Values.

	Disturbance Values		
Feedback Function	-.25	.00	.25
Linear	-.24748	.00109	.25208
Nonlinear	-.11477	.00055	.11805

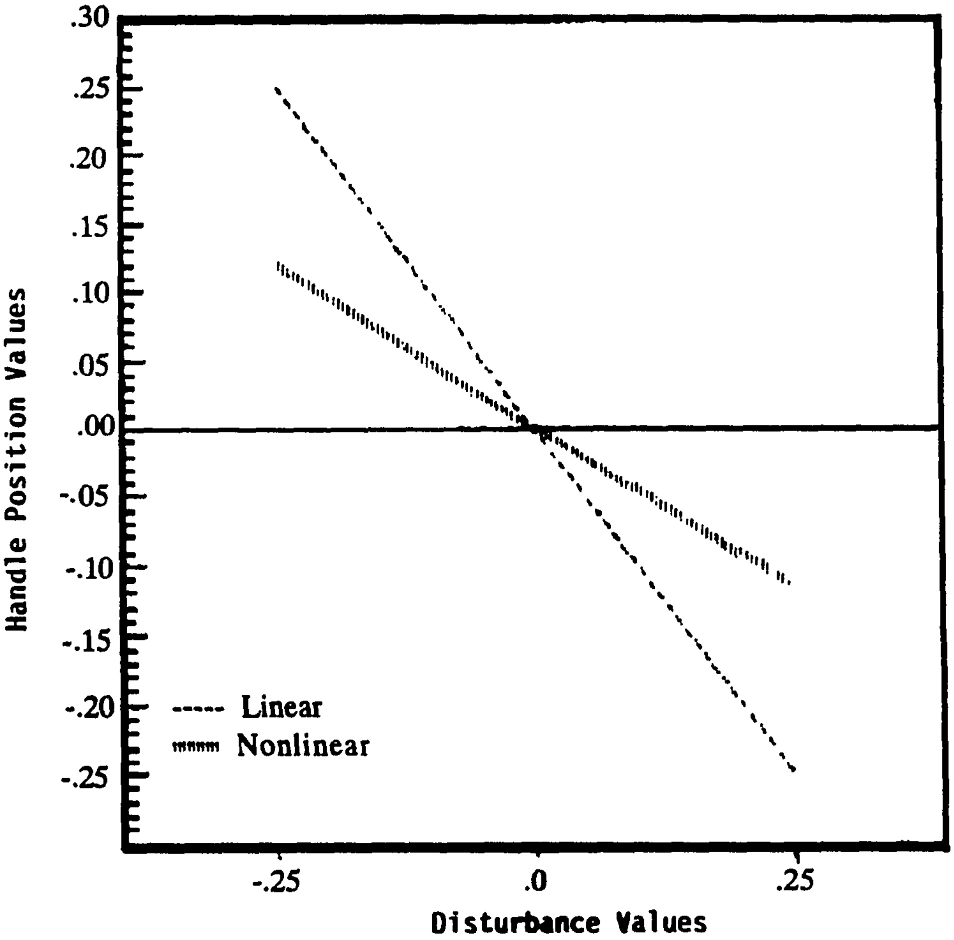

Figure 11. Interaction of feedback function and disturbance values on measures of output (handle position values).

Hypothesis Three: Person Function

Hypothesis three predicted that, despite the observation of changes in the relationship between **D** and **O** consequent to a change in feedback function, the person relationship would remain unchanged. As a first step, this predicts that the subject would remain a control system, with cursor position as the controlled variable. Since $\underline{r}$ (o,-d) > +.99 for all nonlinear trials, we see that all subjects met this expectation.

Next, the hypothesis that the mathematical form of the person function remains constant was tested. Equation 2b was selected to represent a model of the person relationship, based upon past research findings. It was predicted that regardless of the feedback function condition, changes in output, as defined by changes in handle position, would always be proportional (a linear relationship) to the area under the error curve. The observation of linearity would suggest that the person function remained fundamentally the same in form despite the non-linearity of the relationship between disturbance and output in the non-linear feedback function condition.

The test of this hypothesis began by examining the last test trial, for each subject and in each of the two feedback function conditions, in terms of the observed deviations (error) of the cursor position to the left or right of the target location at center screen. For every instance in the test trial in which the cursor deviated to the right or left of the target for periods equal to or greater than 2 s, the area under this error curve was calculated every 1/20th of a second (recalling that error can vary from -.5 to +.5 in screen units) beginning at a point when error was zero and until error again was reduced to zero. Also calculated was the corresponding change in handle position, as compared to its value at the beginning of the 2s (or greater) interval, every 1/20 s. A 2 s interval was used to test the linearity of the relationship between change in handle position (hereafter symbolized ^ O) and area under the error curve; this provided 40 error curve area values and 40 corresponding change in handle position values per second for each test. The best fit regression line for each of these data strands occurring in a single test trial was calculated; Figures 12a-b and 13a-b present the typical resulting analysis of a single test trial in each of the two feedback function conditions for a random subject.

For each subject, the resulting slopes of the analyzed test trial were recorded, along with the Pearson correlation coefficients between change in handle position and area under the error curve. As can be seen by the presentation of the sample data in Tables 6 and 7, slopes were negative and correlations approached -1.0, regardless of the feedback function, as expected. Table 8 contains sample data for a third condition, explained below.

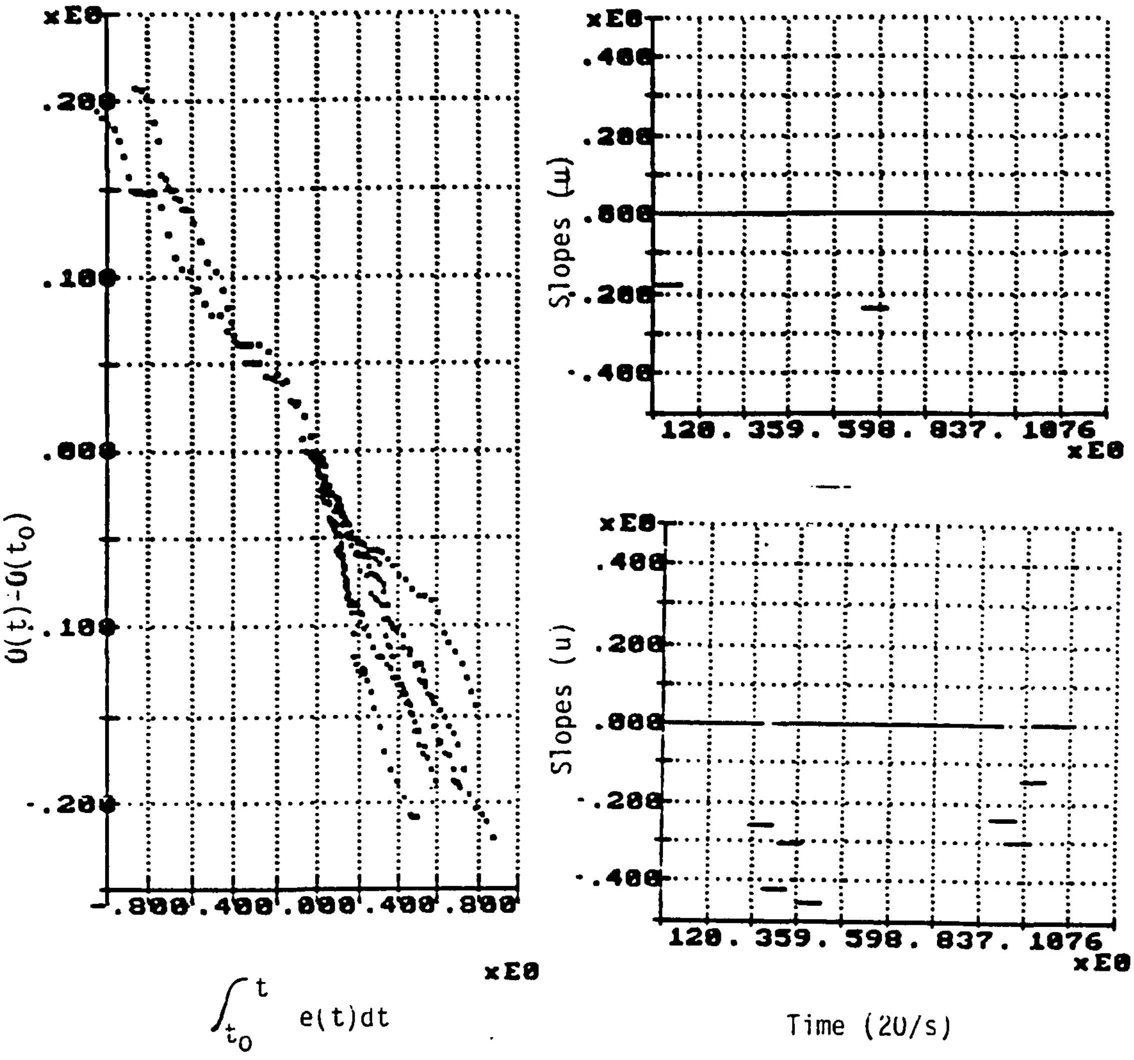

Figure 12a. Regression analysis (left) examining the relationship between changes in output and the area under the error curve, and the corresponding slope values (right), from test trial 2 of subject 5 in the linear condition.

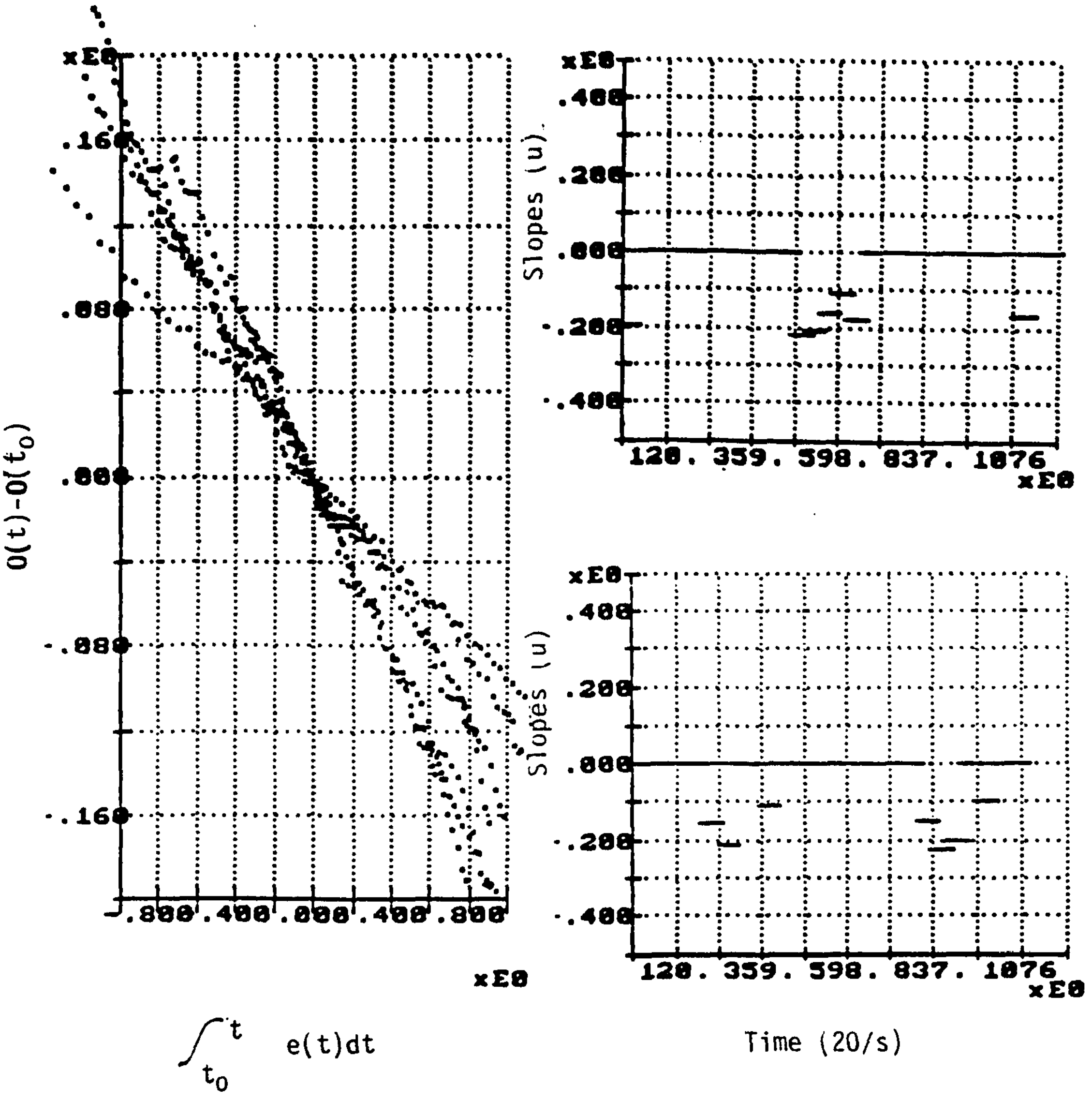

Figure 12b Regression analysis (left) examining the relationship between changes in output and the area under the error curve, and the corresponding slope values (right), from test trial 3 of subject 5 in the linear condition.

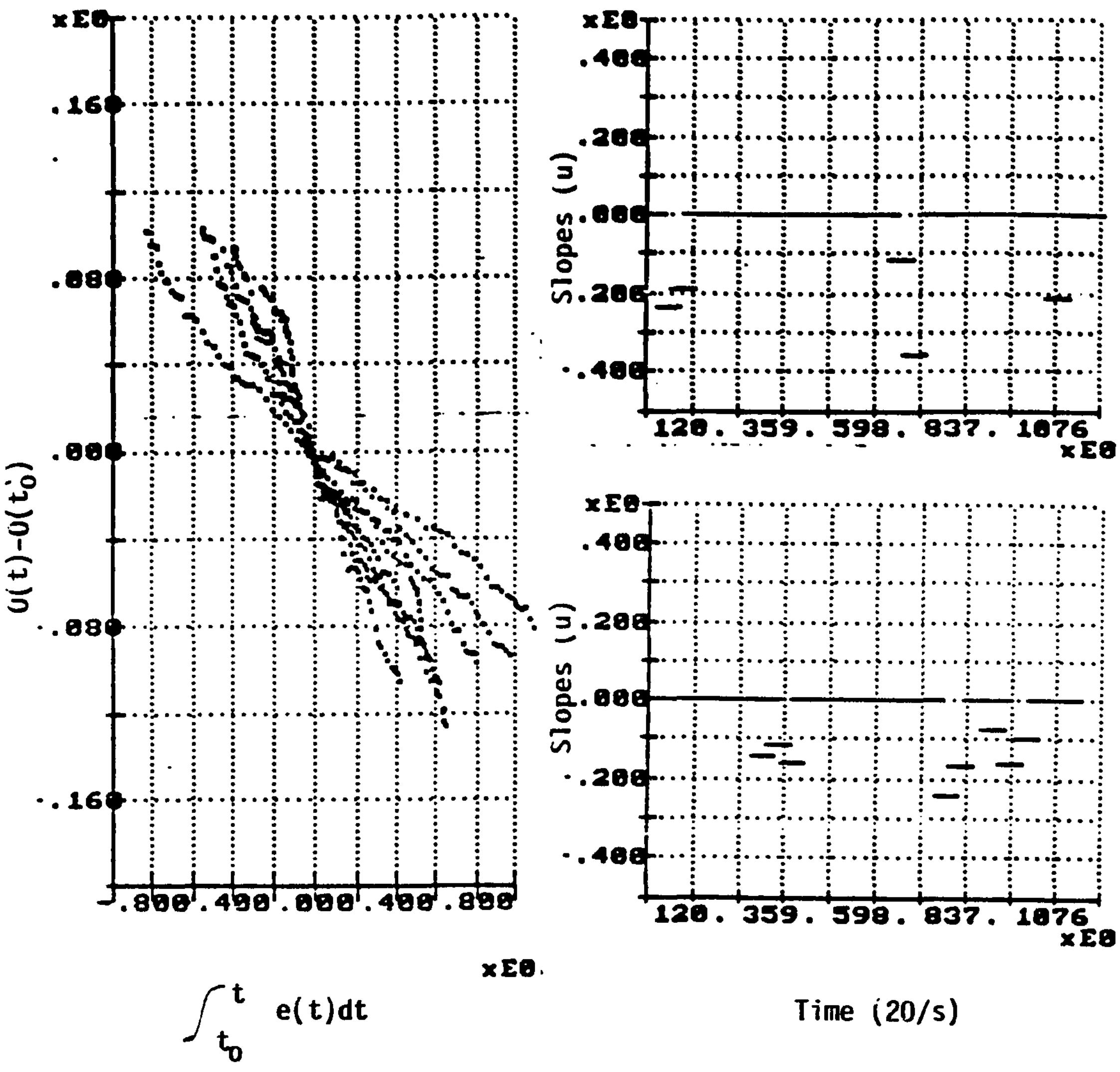

Figure 13a Regression analysis (left) examining the relationship between changes in output and the area under the error curve, and the corresponding slope values (right), from test trial 2 of subject 5 in the nonlinear condition.

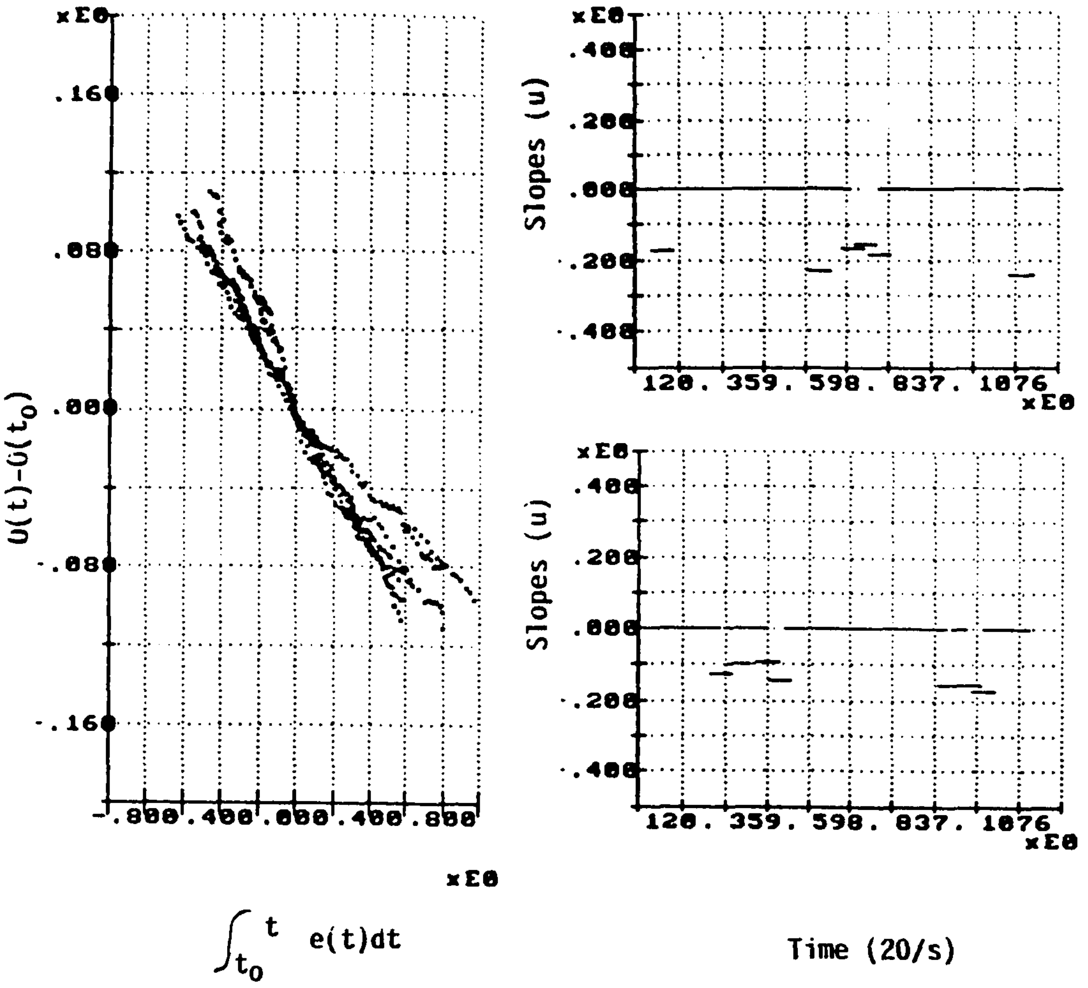

Figure 13b Regression analysis (left) examining the relationship between changes in output and the area under the error curve, and the corresponding slope values (right), from test trial 3 of subject 5 in the nonlinear condition.

Table 6

Correlations between changes in output and error curve area and the corresponding slopes of the left and right sided error data-strands for linear test trial 5 of subject 9.

Left		Right	
R ^O, Area	Slopes	R ^O, Area	Slopes
-.9983	-.1620	-.9842	-.1641
-.9964	-.2027	-.9862	-.1787
-.9970	-.2153	-.9986	-.1980
-.9965	-.1200	-.9996	-.1674
-.9932	-.1080	-.9954	-.1564
-.9892	-.1065	-.9811	-.1098
-.9948	-.0761	-.9949	-.1936
-.9887	-.1682	-.9639	-.1806
-.9947	-.1716	-.9957	-.1475
		-.9978	-.1152
		-.9852	-.1014
		-.9892	-.0874

Table 7

Correlations between changes in output and error curve area and the corresponding slopes of the left and right sided error data-strands for non-linear test trial 5 of subject 9.

Left		Right	
R ^O, Area	Slopes	R ^O, Area	Slopes
-.9958	-.0675	-.9895	-.1442
-.9803	-.0911	-.9937	-.1213
-.9505	-.0332	-.9984	-.1358
-.9972	-.2040	-.9981	-.1704
-.9840	-.0907	-.9966	-.0796
-.9888	-.1144	-.9920	-.0562
-.9964	-.1079	-.9974	-.0730
-.9850	-.1787	-.9973	-.0617
-.9978	-.1336	-.9952	-.1347
-.9981	-.1060		

Table 8

Correlations between changes in the effects of output and error curve area and the corresponding slopes of the left and right sided error data-strands for nonnon test trial 5 of subject 9.

Left		Right	
R ^o, Area	Slopes	R ^o, Area	Slopes
-.9927	-.1534	-.9811	-.1474
-.9971	-.1569	-.9966	-.2381
-.9612	-.0417	-.9967	-.1846
-.9941	-.1523	-.9894	-.1441
-.9933	-.2161	-.9939	-.1464
-.9921	-.2168	-.9935	-.1338
-.9980	-.1403	-.9969	-.1540
-.9931	-.1324	-.9974	-.0950
-.9928	-.1804	-.9864	-.1265
-.9969	-.2127		

Finally, the author tested the hypothesis that the constant of proportionality relating changes in behavior to the area under the error curve would have the same value under the linear and nonlinear conditions. This requires a specification of what is meant by "behavior." Consider first the linear feedback function conditions. If subjects became organized to minimize cursor variability, then the ratio of the change in the effect of handle position on cursor position (hereafter symbolized ^ o) to the area under the error curve may become optimized with practice. Consequently, a change in the feedback function, if it is to be accompanied by the same optimal ratio, will be accompanied by a different ratio of change in output (^ O) to the area under the error curve. From the investigator's viewpoint, the relevant phenomena of interest would be typically identified as the subject's overt behavior, that is, changes in handle position (^ O), in the various feedback function conditions. However, control theory presents the notion that subjects control not their output, but their input. Therefore, the data obtained from a subject's test trials in the nonlinear feedback function condition was examined both in terms of ^ O, and in terms of ^ o, a "condition" arbitrarily labeled <u>nonnon</u>. This alternate view is required for the nonlinear condition only, because in the linear condition this analysis would be redundant, since for this condition o = O by definition. The nonnon regression analysis is depicted in Figure 14.

The data-strand slopes obtained from the analysis of each of the three conditions above, were expected to represent an estimate of the constant of proportionality in

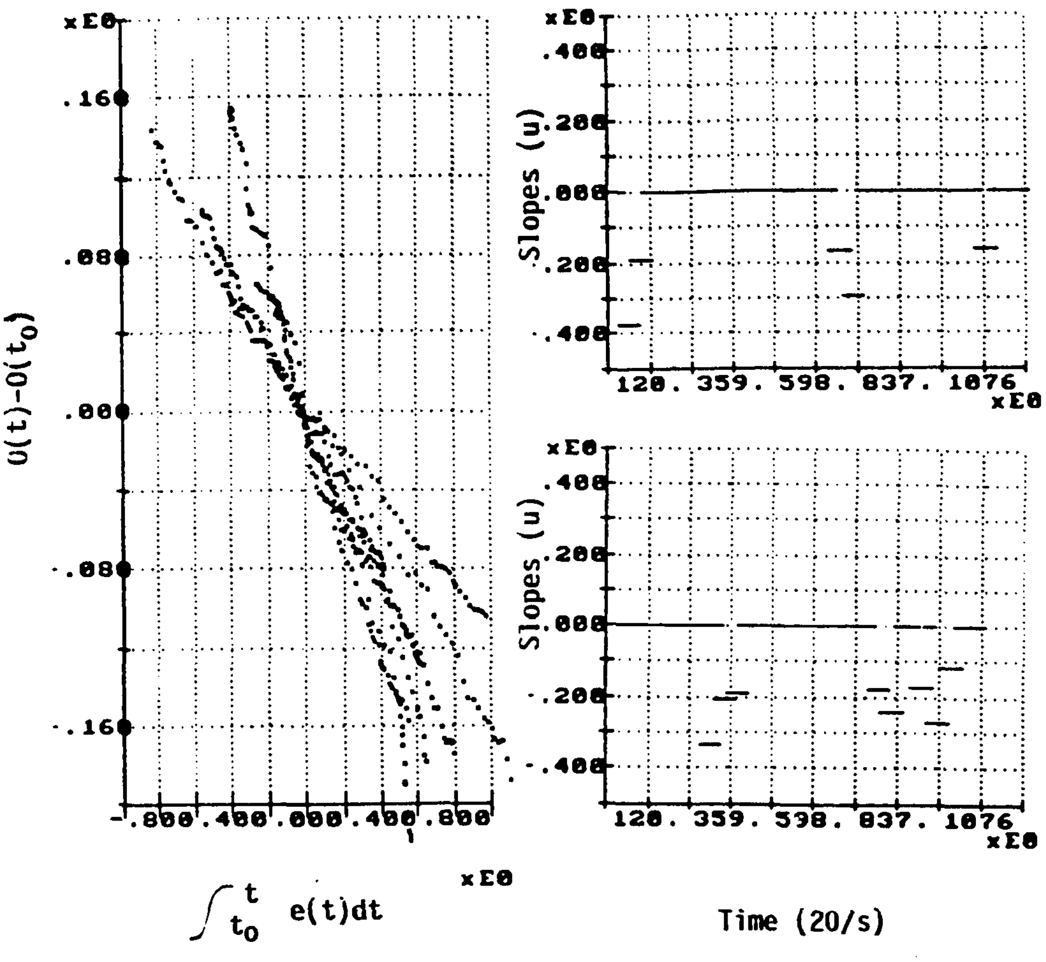

Figure 14a Regression analysis (left) examining the relationship between changes in the effects of output and the area under the error curve, and the corresponding slope values (right), from test trial 2 of subject 5 in the "nonnon" condition.

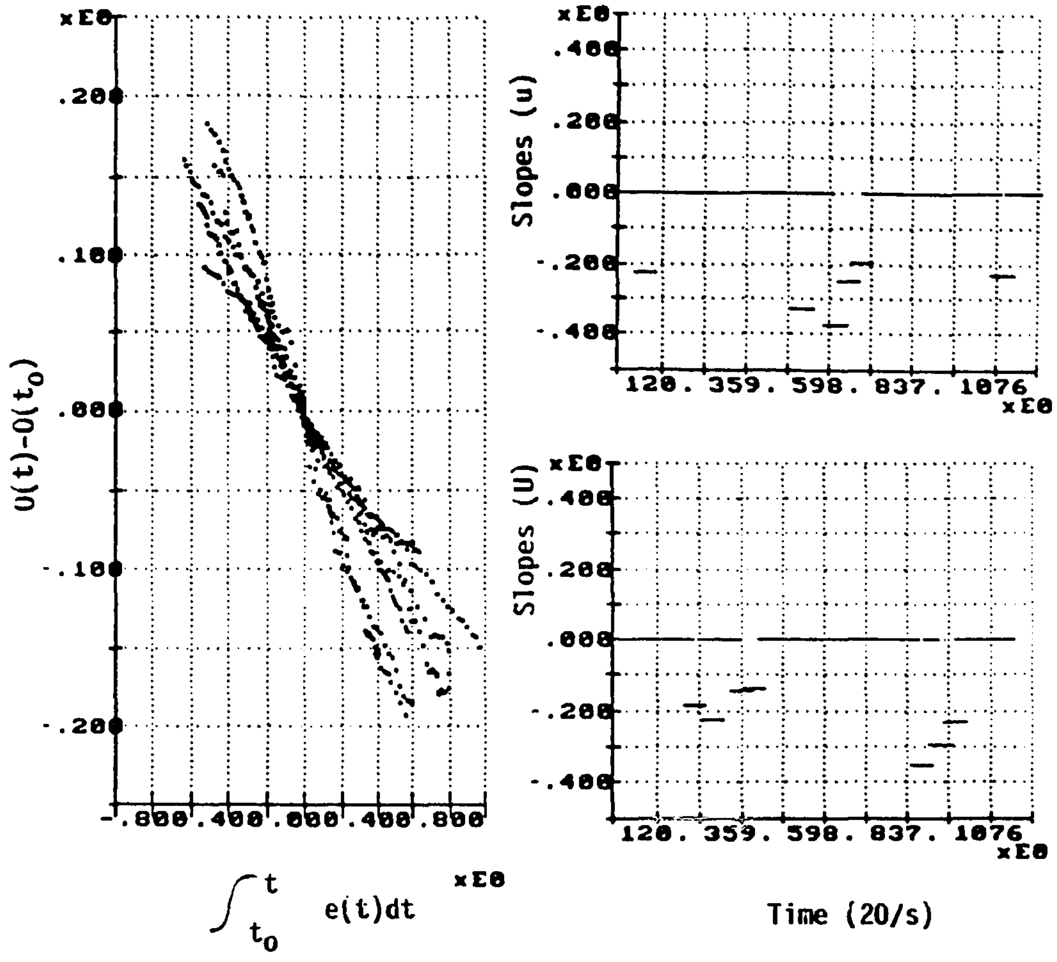

Figure 14b Regression analysis (left) examining the relationship between changes in the effects of output and the area under the error curve, and the corresponding slope values (right), from test trial 3 of subject 5 in the "nonnon" condition.

the person function equation for that particular subject. Since it was important to gain a good estimate of this constant of proportionality for each subject, calculations for the data strand analysis did not include the rare occurrance in which the correlation between changes in handle position and the area under the error curve was not negative or better than -.95. That is, as estimates of the constant of proportionality, analysis utilized only those slopes that derived from instances in which the area under the error curve explained at least 90% of the variance of changes in handle position. This tact was further justified by the observation that on nearly all occasions in which these correlations occurred, the value of the unseen disturbance was near its extreme, a point at which it was either just beginning or just completing a change in direction, and therefore slowly changing. Subsequently it was believed that during these brief times, subjects' control of cursor position, as seen from the experimenter's perspective which focused on overt behaviors, such as handle movement, might temporarily lapse.

If it is true that the data-strand slopes represent the subject's constant of proportionality, it was expected that calculation of the variance of the data-strand slopes, as produced from each subject's last test trials, would reveal a very small and near zero variance. The data, did in fact, match this expectation. Table 9 presents each subject's slope variances, for left and right sided errors, in the two feedback function conditions, as well as the alternate, nonnon condition. In the linear feedback function condition, the variances of the subjects' left slopes ranged from .00000-.02510, and the variances of their right slopes ranged from .00070 to .01620. For the nonlinear condition, the observed range was .00080 to .01110 for the left, and .00090 to .02330 for the right. In the case of the nonnon analysis, the variances of the subjects' left slopes ranged from .00020 to .01090 and variances of their right slopes ranged from .00010 to .01690. Columns 2 and 3 of Table 10 summarize the ranges in slope variance by condition.

Correlated groups t-tests were conducted to separately examine the left and right mean slope-variance values for the linear ($\underline{M}$ = .0051, left; $\underline{M}$ = .0046, right) versus the nonlinear ($\underline{M}$ = 0042, left; $\underline{M}$ = .0049, right) conditions, and the linear ($\underline{M}$ = .0051, left; $\underline{M}$ = .0046, right) versus the nonnon ($\underline{M}$ = .0033, left; $\underline{M}$ = .0043, right) conditions (Table 10, right). As summarized in Table 11, no significant differences were revealed; linear versus nonlinear, $\underline{t}$ = .662, $\underline{p}$ > .52, left and $\underline{t}$ = -.169, $\underline{p}$ > .87, right; linear versus nonnon, $\underline{t}$ = 1.070, $\underline{p}$ > .30, left; and $\underline{t}$ = .157, $\underline{p}$ > .88, right.

Table 9

Slope variances in the final test trial for the linear, nonlinear and nonnon conditions.

Subject	Linear		Nonlinear		Nonnon	
	Left	Right	Left	Right	Left	Right
1	.0063	.0046	.0019	.0084	.0023	.0071
2	.0012	.0003	.0050	.0102	.0029	.0135
3	.0012	.0019	.0008	.0020	.0013	.0019
4	.0023	.0021	.0065	.0096	.0109	.0026
5	.0079	.0035	.0027	.0019	.0033	.0019
6	.0182	.0056	.0008	.0014	.0009	.0033
7	.0251	.0007	.0111	.0019	.0017	.0089
8	.0011	.0162	.0052	.0018	.0039	.0011
9	.0022	.0014	.0025	.0017	.0028	.0016
10	.0041	.0044	.0019	.0161	.0069	.0169
11	.0027	.0035	.0011	.0017	.0005	.0015
12	.0023	.0014	.0021	.0023	.0041	.0083
13	.0049	.0015	.0027	.0041	.0047	.0087
14	.0033	.0088	.0060	.0035	.0066	.0001
15	.0048	.0134	.0018	.0009	.0010	.0015
16	.0026	.0013	.0032	.0023	.0002	.0004
17	.0041	.0040	.0047	.0014	.0021	.0019
18	.0065	.0067	.0111	.0233	.0040	.0022
19	.0003	.0034	.0079	.0014	.0042	.0025
20	.0000	.0040	.0041	.0012	.0023	.0009

Table 10

Range and means of slope variances for left and right sided errors as observed in the linear, nonlinear and nonnon conditions.

	Minimum	Maximum	Mean
Linear			
Left.	.00000	.02510	.0051
Right	.00070	.01620	.0046
Nonlinear			
Left	.00080	.01110	.0042
Right	.00090	.02330	.0049
Nonnon			
Left	.00020	.01090	.0033
Right	.00010	.01690	.0043

Table 11

Correlated groups t-tests of the linear versus nonlinear and linear versus nonnon mean slope-variances.

	df	t	p
Linear vs Nonlinear			
Left	19	.662	>.52
Right	19	.169	>.87
Linear vs Nonnon			
Left	19	1.070	>.30
Right	19	.157	>.88

Table 12

Slope means and grand means for the final test trial in the linear, nonlinear and nonnon conditions.

SS	Linear		Nonlinear		Nonnon	
	Left	Right	Left	Right	Left	Right
1	-.1851	-.2531	-.1192	-.1543	-.1194	-.2125
2	-.1143	-.1169	-.1532	-.1560	-.1485	-.1806
3	-.1050	-.1687	-.0863	-.1055	-.1077	-.1339
4	-.1578	-.1611	-.1423	-.1570	-.1765	-.1731
5	-.1847	-.1537	-.1864	-.1251	-.2042	-.1736
6	-.2545	-.2168	-.1425	-.1203	-.1444	-.1556
7	-.3228	-.2608	-.1695	-.1839	-.1957	-.2090
8	-.1997	-.1980	-.1503	-.1601	-.2029	-.3330
9	-.1478	-.1500	-.1127	-.1086	-.1603	-.1522
10	-.2027	-.1934	-.1988	-.2292	-.2599	-.2881
11	-.1876	-.1710	-.0667	-.1052	-.0908	-.1521
12	-.2089	-.2112	-.1216	-.1534	-.1285	-.2317
13	-.2192	-.2707	-.1446	-.1402	-.1724	-.2220
14	-.2503	-.2203	-.1339	-.1530	-.1418	-.1582
15	-.1563	-.1949	-.1070	-.0968	-.1542	-.1168
16	-.1540	-.1704	-.1109	-.0991	-.1334	-.1143
17	-.2278	-.2427	-.1483	-.1392	-.1866	-.1851
18	-.2290	-.1974	-.2260	-.1808	-.2730	-.1967
19	-.2424	-.3076	-.1584	-.1338	-.1796	-.1596
20	-.2190	-.3162	-.1950	-.2368	-.2487	-.2877
Grand Means	-.1962	-.2114	-.1437	-.1469	-.1714	-.1916

After identifying the mean slope values for left and right sided errors of each subject in each of the conditions (Table 12), correlated groups t-tests were also conducted to evaluate differences in mean slope-means (Table 12, bottom) between the linear (M = -.1962, left; M = -.2114, right) and nonlinear (M = -.1437, left; M = -.1469, right) feedback function conditions. This revealed significant effects for both left, t = -4.985, p < .0005; and right t = -6.072, p < .0005, mean slope-means. Since this analysis looks at differences between linear and nonlinear conditions in terms of overt changes in behavior (^ O, or changes in handle position) to area under the error curve, this finding was hardly surprising. However, when this analysis was then repeated to compare the linear (M = -.1962,left; M = -.2114, right) and nonnon (M = -.1714, left M = .-1916, right) data, nonsignificant findings for both left t = -2.029, p > .057, and right, t = -1.444, p > .165, mean slope-means were revealed.

Table 13

Correlated groups t-tests of the linear versus nonlinear and linear versus nonnon mean slope-means.

	df	t	p
Linear vs Nonlinear			
Left	19	-4.985	<.0005
Right	19	-6.072	<.0005
Linear vs Nonnon			
Left	19	-2.029	>.057
Right	19	-1.444	>.165

CHAPTER IV

DISCUSSION

Interpretation of Findings

Discussion of the findings in this study may be viewed in terms of their relevancy to behavioral science within the context of current conventions in behavioral research, which are based upon a stimulus-response model, and also in regard to their contribution to the existing control systems literature, research efforts and their expansion.

In an effort to first establish a relevant focus it may be helpful to momentarily restate the aim of the experimental task, since the fact that subjects in this study maintain cursor roughly at center screen when told to do so, despite disturbances, might easily be dismissed by the reader as trivial, if not blatantly obvious. The area for critical focus in this investigation was not upon what the subject accomplishes, but on how the subject does it. From the control systems perspective, subjects in the compensatory tracking task were hypothesized to be controlling the variable of cursor position. It was hoped that if we could empirically observe relationships which supported this claim, we might reasonably expect there to be other unapparent relationships in the person-environment interaction which also are not explainable by S-R theory. As in the manipulation check, the hypothesized relationships would not be expected to be immediately obvious to the observer, and clearly, if they exist, are not trivial.

The initial and prerequisite hypothesis in this study did indeed produce unequivocal evidence which strongly supported the notion that subjects were operating as control systems in this task. Regardless of manipulations in the feedback function and despite the influences of an unseen disturbance, all subjects produced near perfect correlations between disturbance and handle position and also canceled virtually 100% of the variance in cursor position. These findings are completely consistent with those of existing control systems studies. More important, these findings largely contradict the expected relationships predicted by S-R theory, since output predictably co-varies not with the cursor, the presumed stimulus, but with the disturbance, which was not seen by the subject.

In support of hypothesis two, data from the experimental task revealed a highly significant interaction of the different feedback function conditions with the same disturbance, on measures of the subjects' overt behaviors, or handle position.

Armed only with this observation of the significant interaction, and given conventional practice in behavioral science, we are inclined to conclude that this interaction reveals, and can be explained by, the existence of some mediating process within the subject.

Yet if, as the conventional view in behavioral science dictates, that changes in stimulus-response relationships in the environment reflect corresponding changes in the person, what can be said about the apparent contradiction of findings observed in the case of hypothesis three in this study, which analyzed the experimental data from the perspective of a hypothesized control systems model of person functioning, and revealed <u>no</u> corresponding significant differences between feedback function conditions? It is <u>impossible</u> for a stimulus-response model to explain this contradiction. From the viewpoint of control theory however, this contradiction is not only explainable, it is expected.

The central focus of conventional behavioral studies procedurally corresponds to our experimental manipulations of the environment (feedback function and the introduction of a disturbance, D), and to the observation of subsequent changes in subject output (O, or handle position) following these manipulations. From the control systems perspective however, the disturbance, **D**, in and of itself is not of interest to our subjects. We can say that this is true for a number of reasons. First, as supported by the findings in both hypotheses one and three, the subject is judged to be controlling the value of some variable, in this case cursor position, and therefore is only concerned about <u>actual</u> influences of a disturbance, **d**, upon that variable.

Further, the subject has no direct access to **D** and therefore can only be aware of it through its effects upon the cursor. A similar statement may be made as well about changes in **O**. While the subject is certainly privy to **O**, since the subject is producing these outputs, all that really matters to the subject is the ultimate <u>effect</u> of that output, **o**, upon the controlled variable. The only knowledge our control system subject has about his own output, is via its effect upon input (e.g., the value of cursor position). More accurately, since it is <u>sum</u> of the effects of both output and disturbances that influence a controlled variable, the subject has no knowledge of the relative contribution of these influences to cursor position, but only has information regarding cursor position itself.

Also essential to this understanding is the fact that the actual effects of the subject's output are not entirely under the control of the subject but are also influenced by physical laws, a property of the environment. For example, because each of the two feedback function conditions in this study involved two entirely different functional relationships between the subjects' output (handle position) and its actual effects upon the controlled variable, a change in handle position of .1 would have different eventual effects on cursor position in each condition. Restated, it is the physics of the situation that determine how outputs, **O**, and disturbances, **D**, will affect a controlled variable. Further, the form of the functional relationships between **D** and **O** depends strictly on the environmental relationships, existing at the time, between **D** and **d**, and **O** and **o**. To conclude that this functional relationship between them is a property of the person is a mistake.

In research investigations, when we manipulate variables in the environment, alter the setting, the procedure, or the apparatus, what we may unwittingly be changing is the feedback function (the functional relationship between **O** and **o**), or alternately, the disturbance function (the functional relationship between **D** and **d**). When experimenters manipulate variables in the environment, and consequently observe changes in the observable relationships between manipulations of **D** on measures of **O** it may very well be that this does not lead to effects upon the person, but to a variable that the person is controlling. Statistically significant effects that we find in such investigations may make it appear as if something in the person relationship has changed, when in actuality it may reflect nothing more than changes in rather uninteresting relationships among aspects of the environment.

On the basis of the evidence in this investigation it would not be unreasonable to conclude that the significant interaction observed in hypothesis two is not really relevant to person processes, but is more likely to reflect nothing more than the fact that our attention has been drawn toward this illusory distraction of physical relationships occurring in the environment. As supported by the statistical evidence evaluated for hypothesis one, because subjects in this study are operating as control systems, the relationship between o and d remained stable such that **o** = **-d** across feedback function conditions, even when the relationship between the manipulated variables (**D**) and what we measure (**O**) changed. Stated alternately, because the subjects controlled cursor position in both feedback function conditions, the resulting interaction between the disturbance and the feedback function occurs.

Since the relationships observed in the data for hypothesis one remained stable, as evidenced by correlations of .99 or better between the effects of output on the controlled variable and the negative of the effects of the disturbance upon the controlled variable, regardless of the experimental condition, it suggests that the basic principles of control system operation are unaffected by the nature of the functional relationship between **O** and **o**. The central focus in this study, of course, was to more rigorously examine this belief via a hypothetical model of the person relationship as in hypothesis three, and to do so in particular when conventional analysis concludes that significant changes have occurred.

The expectation that the form of the person function would remain invariant across experimental conditions was supported. In both linear and nonlinear experimental conditions, as well as in the nonnon representation, analysis of subjects' data-strands revealed proportional/linear relationships between measures of changes in handle position (changes in its <u>effect</u> in the case of the nonnon analysis) and cumulative area under the error curve. The observation of linearity in all conditions supports the hypothesis of invariant process in person function, since in the case of the nonlinear/nonnon condition the 'stimulus' is clearly not linear. Analysis of slope means between conditions also supported the hypothesis when data were viewed from the perspective of ^ o, which entailed comparisons of the linear and nonnon condition. This perspective, as the reader may recall, regards the data in a way that we expect would be relevant to the subject, in terms of input to the subject's perceptual system. As in the case of hypothesis two, when these same data were analyzed from the perspective of the observer in terms of manifest output, ^ O, the comparison between these conditions, linear and nonlinear was significant. Again, this is not surprising, since what the investigator typically observes and measures (^ O in the environment) has little to do with what the subject perceives in the experimental task (^ o as perceptual input). The subject's "behaviors" as regarded from the standpoint of person processes were unaffected by the experimental manipulation.

The findings and data for hypothesis three merit some further comment relevant tc control systems literature. As presented in earlier text, control theory contains a built-in expectation of individual differences since, for example, no two nervous systems are identical. On this basis, it was not expected that the parameter in our person equation (2b) would be a constant in the strict sense, since depending upon relative sensitivity to error, different subjects could reasonably be expected to produce somewhat different slopes. Alternately, during occasional temporary lapse in controlling the variable of interest, some variability in slopes could be expected. Although comparisons of the slope-variance means between the experimental conditions revealed no significant differences statistically speaking, visual examination of single subject data showed enough variability in slopes to be considered perplexing from the perspective of control theory, which would expect even much smaller variability than observed. While it was possible that the problem lay in the impreciseness in the equation utilized as a model of the person relationship, another explanation seemed more plausible based upon examination of the data in the nonlinear condition. In this condition, the nature of the nonlinearity of the relationship between **O** and **o** was such that the corresponding plot of handle position

(**O**) against the disturbance (**D**), as was depicted earlier in Figure 8, reveals a function that is nearly linear in the center, with a slope of -2, and which is also nearly linear at each end, but with considerably smaller slopes. The best fit line through each of these three segments would reveal a much steeper slope for the center portion than for the segments at each end. It is suspected that depending upon the location of handle position, it may have been necessary for subjects, in order to remain good control systems for the task, to reorganize at each of these segments, thereby leading to slightly different parameters, and thus accounting for the variability in the slopes.

Limitations

While overall, the results of the study clearly supported the experimental hypotheses, the investigation was not without flaws or limitations. No clear threats to internal validity were identified. Although it is true that some concern may be raised about the choice of volunteer versus randomly selected subjects, this is certainly a minimal concern given the consistent and well-established findings regarding tracking task studies in control theory research on a variety of populations.

Procedurally, some difficulties did arise. As noted earlier in the presentation of results, there were some occasions in which the correlations of ^ **O** (changes in handle position) and ^ **o** (changes in effects of handle position upon cursor) with error curve area, departed from the expected value of -.95 or better; very rarely, some of these correlations were even strongly positive. Since it was necessary to obtain a reliable estimate of the person parameter for the analysis in hypothesis three, these correlations were initially disturbing, as their inclusion in the data strand analysis might distort this parameter. Further, their presence, unless explainable, raised suspicions about the hypothesis at the outset. Closer exploration revealed however that these correlations predominantly occurred at extreme disturbance values, at which time there would be fairly slow change in the disturbance as it approached or completed a change in direction. This observation, while not anticipated, was also not surprising. During this time subjects could become somewhat lax in controlling cursor position without it resulting in much departure from center screen. In short, this appears to be a limitation of the parameters of the task as articulated in this investigation, and not of the theory. In future studies the problem may be largely remedied by modifying disturbances programmatically such that a minimum rate of change is established, or by experimentally establishing the range in which this effect occurs and obtaining sample data only from occasions in which rates of change in disturbance exceed this level.

In obtaining good estimates of the person parameter, it was not clear how many trials would be optimal for collecting the data such that the subject would have received enough trials to allow reorganization to stabilize, but not so many that motivation was compromised and subjects might begin controlling for other variables not intended by the investigator. While only one of the subjects' test trials in each condition was utilized to estimate the person function parameter in this study, and while this seemed sufficient to address the research questions entertained here, future efforts to evaluate or to further refine equations of the person relationship in control systems functioning may find that combining the data from several trials reveals a more precise estimate of the parameter.

This study utilized three practice and five test trials. However, since subjects reached criterion largely on the first practice trial without much subsequent variability in performance in later trials, it appears that reorganization and stable performance occurs quite rapidly. Fewer trials may have no adverse effects on the reliability of the data;, however, it must be cautioned that the subjects in this study were judged to be highly motivated volunteers. Less motivated subjects may produce less stable performance or alternately, lose interest when asked to do many trials.

Summarization of Findings

The findings in this investigation provide substantial evidence that subjects are control systems for this task. Critically, the results of this investigation offer unequivocal evidence that the tradition of making inferences about changes within the person based upon the observation of overt changes in behavior following the manipulation of an environmental "stimulus" is a suspect practice. The observation of statistical interactions appears to reveal little relevant data about person processes, particularly given the coexisting finding in this study of nonsignificant changes in measures of person functioning when subjected to the same experimental manipulations.

If humans do in fact operate as control systems, the potential ramifications for behavioral science are enormous.

Application

The subjects' actual accomplishments in this tracking task may be of little, if any, value to the behavioral sciences, except perhaps within the confines of motor skills performance, in the design of devices made for man-machine interaction, or in contexts where target-tracking skills are a critical concern, such as military or pilot training. The main thrust of this investigation however, was aimed at the level of testing general assumptions about how we conceptualize and subsequently conduct the science of behavior, and it is at this level that the findings may have profound implications for the field of psychology and the science of behavior.

The tracking task employed in this research project provided a context by which the basic principles of control systems operation, and the environment and person relationships subsumed within it, may be easily defined and observed in a simple task. The vast majority of human behaviors, of course, take place in much less confined circumstances and, in particular, occur without the advantage of mutual agreement between observer and actor as to the identity of the controlled variable.

However, the existence of feedback is found in virtually all human behavior; it may be reasonably hypothesized therefore, that humans are control systems for a great variety of variables. If this is true, the next logical step would be to attempt to examine control systems functioning across a variety of behaviors with particular focus upon the development of strategies and techniques for identifying controlled variables.

If humans are control systems, they will effectively cancel the influence of disturbances upon a controlled variable. As this study has demonstrated, conventional experimental observations of a subject's behaviors in relation to a stimulus are of no assistance in identifying the variable the person is controlling. Yet it is this variable that may truly be the variable of interest. Why?

As we have seen in hypothesis three of this investigation, when properly defined, the relationships between a controlled variable, any disturbance to that variable, and the output of the person are quite predictable. Regardless of complexity, once the controlled variable and the reference value have been identified, these relationships would be quite evident, and not very mysterious.

While admittedly it is a large leap of faith at this point to say that subjects, or people in general, are control systems for tasks beyond the one investigated here, the idea is no more untenable than the notion that people are driven by stimulus-response laws. For better than a half a century a S-R model of behavioral organization has dominated the field of psychology, both in theory and research methodology. As is any choice of research hypothesis, this preference is an arbitrary one, subject to falsification.

The relationships that were observed in this investigation offer credence that the S-R view may be an antiquated concept, no more fitting of human behavior than the belief in a flat earth fits the experience of round-the-world travel. As the findings in this study suggest, our current paradigm of the basic nature of behavioral organization no longer fits our experience. As we are reminded by Socrates, "The most important part of any inquiry or exploration is its beginning. As has often been pointed out, if one makes a false or superficial beginning, no matter how rigorous the methods followed during the succeeding investigation, they will never remedy the initial error" (cited in Schumacher, p. 7). Our failure to make substantial progress in the behavioral sciences, particularly in terms of practical applications in its prediction, modification and treatment, may have less to do with the complexity of the human organism, and more to do with faulty initial assumptions and the application of the wrong model.

Psychology, as any other legitimate science, has historically undergone evolutionary metamorphoses, in terms of defining its nature, subject matter, and methodology (Kuhn, 1962, 1970). It is essential to separate science from dogma, and it may well be time for a paradigm shift. If scientific inquiry demands that we evaluate against the evidence, why not then operate instead from a control systems orientation, which at least in this study, shows an ability to better account for the data and our subjects' behavior than the conventions of tradition to which we now adhere.

The field of psychology has historically fought an uphill battle to become established as a legitimate science. Concerns that precipitated the recent reorganization crisis of the American Psychological Association are evidence of how tenuous that establishment is even today. The core of scientific psychology rests on the premise that stimuli external to an organism stimulate the organism to emit responses (behavior). Resistance to disturbing this core is understandable. However, as argued by the findings in this investigation, the primary contribution of this conventional model appears to be not so much its power in explaining behavior, but in its ability to provide a means by which this behavior can presumably be experimentally subjected. The constructs of stimulus and response provide convenient ways to divide behavior into the dependent and independent variables necessary for scientific analysis. What has been forgotten is that these terms are merely constructs, and poor ones at that. They not only are not equivalents of the person's behavior, but as suggested by the findings in this study, they also offer no illuminative explanation of how persons behave, allegedly the goal of the behavioral sciences.

As has been unquestionably demonstrated in this project, research application of control theory in no way violates or compromises methodological or statistical standards of rigorous science. This may be an especially important point, since control theory also posits that control systems are purposeful. Such teleological notions have historically been rejected as inappropriate subject matter in psychology, as it has been mistakenly assumed that one could not provide clear operational definitions for future stimuli such as "intention."

If control systems theory proves to be a viable model in behavioral science, it does not mean that research to date has been wasted effort, but it may mean reinterpretation of the findings and what we only think we know about human behavior . For example, behavioral interventions may be successful only in so far as they serve to assist the person's efforts to reduce deviations of some controlled variable from its reference level. As such, the extinguishing of phobias via behavioral techniques such as hierarchical desensitization and relaxation may work not because they "counter-condition" the individual, but because they may directly impact upon a controlled variable "sympathetic activation", by returning deviations of that variable to a level consistent with an individual's reference level, and therefore no longer requiring the individual to produce other avoidant actions designed to maintain this level.

A readjustment in focus toward a control theory model of behavioral organization may assist in reinstating a connection between research and practice. Practical applications of a control systems theory may prove useful in the study and analysis of psychophysiological disorders, and as a means of shedding new light on certain clinically relevant behaviors that have previously been poorly understood when examined from the perspective of more traditional models of behavioral organization. Control theory may offer a valuable shift in perspective in the conceptualization of, and assessment/interventions with, the mentally ill or neurologically impaired. For example, are the perceptual input or output components of the person producing erroneous signals, interfering with reorganization, or themselves magnifying or producing error? Or perhaps, alternately, is there an inability to designate a controlled variable? The applications of control theory may be far-reaching, and it is only the lack of serious attention to the model which currently conceals both its potential and its limitations.

Proponents of Control Systems Theory suggest that if we chose to ignore scientifically observed relationships that importantly contradict those which we would expect from the S-R tradition, and that if we continue to study and analyze human behavior with an outdated methodology built from assumptions that control for human behavior flows from the environment in the form of stimuli to which the individual responds, we may make no further significant progress in understanding behavior and its organization. The findings in this study suggest that it may be time to reevaluate these traditional theoretical and, consequently, methodological assumptions about behavioral organization. Until we incorporate the dynamic elements of feedback, physical time and the phenomena of purpose into our theories and experimental methodologies we limit this understanding.

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Appendix A

Informed consent form

As a subject in this study you will be asked to control the position of a cursor on a video screen using a joystick similar to ones you might have seen used for home video games. The task will consist of an overlapping series of one-minute trials. The total time required for your participation is estimated to be approximately 30-60 minutes, depending upon how precisely you perform the task.

The purpose of this experiment is to gather very exact information about how people do what they do in this particular tracking task. We will then use this information to see if it more closely fits our current beliefs about how people do this task or an alternative model, based on Control Theory. Because our assumptions about behavior guide the methods we use to conduct and interpret research of behavioral phenomena, our conclusions could be misleading if our basic assumptions are incorrect. General accuracy about the basic assumptions underlying any model of human behavior is therefore a prerequisite to conducting meaningful research in the general study of human behavior.

There is no deception in this experiment and there is no risk posed to you by your participation in it. Your performance on the video task and any other information gathered is absolutely confidential. Information which is recorded is coded only with numbers and is not identified by name. Any publications of results is completely anonymous.

You are free to ask questions about the procedure at any time before or after your participation. If you request it, a summary of the results at the completion of the study will be made available to you.

All instructions that you need for the task will be presented to you on the video screen. You are encouraged to do your very best in following the task instructions closely and are urged to perform the series of trials as precisely as possible from beginning to end. Without your best effort, the results are meaningless. Further, very precise performance on your part will reduce the amount of time required for you to complete the study.

Please sign below to indicate that you have read and understand the above description and explanation and that you consent to participate. You may at any time, and for any reason, choose to withdraw from the study without penalty.

____________________________________ __________________

Signature Date