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ON THE ACCURACY AND RELIABILITY OF PREDICTIONS BY PERCEPTUAL CONTROL THEORY: FIVE YEARS LATER

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This is a demonstration of an idiographic procedure that makes very accurate quantitative predictions of one person's specific actions during a task. In June, 1988, I completed Condition 1 for each of eight different runs of a two-condition pursuit tracking task. Using data from Condition 1, when only the control handle affected the position of the cursor, I estimated the constants in the model of behavior from perceptual control theory, then I used the model to predict the results for Condition 2, when a random disturbance would also affect the cursor. Every five years I will do two of the eight predicted runs; I did two of them in July, 1993. Correlations between 1800 pairs of predicted and actual handle positions were .998 for the first run, and .997 for the second. Data from the model and me were nearly indistinguishable. I briefly discuss some misconceptions about data like these.

Accuracy and reliability are such common features of human behavior that we often overlook our many successes and notice the rare times when we fail. We move food from the plate and into our mouths so easily and precisely that we take the results for granted, noticing instead the rare slips between plate and lip. We routinely maneuver ourselves and our conveyances (such as horses, bicycles, airplanes, and automobiles) from home, to work or play, and back, often over long distances and with no mishaps. The probability of a successful trip is remarkably high; we notice, instead, the rare exceptions.

No matter how vividly they occupy our attention, catastrophic failures while eating, or while traveling, occur only once in many thousands, or

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PCT is discussed on a "Listerv" electronic mail network, the Control Systems Group Network (CSGNet). The Internet address is: CSG-L@VMD.CSO.UIUC.EDU, the Bitnet address is: CSG-L@UIUCVMD.BITNET. The list is also available as a NetNews (Usernet) newsgroup under BIT.SCI.PURPOSIVE-BEHAVIOR..

millions, of successes. Accurate, reliabile results are the rule, even though our behavior occurs in a world that varies in ways we cannot precisely predict. We cannot know in advance the weight and balance of the food on our spoon during each bite, or the states of all of the muscle fibers in our own hands and arms. We cannot know in advance the moment-by-moment conditions of the road, the weather, other drivers, or our own bodies. What we know in advance is the result we intend to accomplish. In the face of inevitable variability in the world, our own actions also vary just as is needed, and we produce the unvarying results that are hallmarks of intentional behavior.

Here, I demonstrate a way to model and simulate intentional behavior and I show that in the long term the model's quantitative predictions are as accurate and reliable as the behavior of the person. I use the model from perceptual control theory (PCT), a theory that explains how people achieve consistent results in a variable world. PCT and some of its applications are described in a foundational book (Powers, 1973) and in edited works and anthologies (Hershberger, 1989; Marken, 1990, 1992; Powers, 1990, 1992; Rodrigues & Lee, 1994). In this paper, I do not attempt to compare PCT with any other major theory of behavior, but I discuss some common misconceptions about PCT and purposive behavior.

Predictions

Data from studies of people in groups are often called "nomothetic." Nomothetic data may allow us to predict things like the average score for a group, or the proportions of people in certain groups who will perform certain classes of actions. For example, we might predict the proportion of first-year university students with a certain score on a standard entrance examination who will join at least one university-recognized social organization and will also maintain a grade average of "B" or higher. However, we cannot predict with certainty whether a particular student with that score will join an organization, or maintain a "B" average, or do both. In contrast, "idiographic" predictions, like those in PCT, pertain to specific individuals. As I apply it here, PCT yields quantitative predictions of the movements a specific person will use to create and maintain (control) an intended result.

General Method

I used the behavioral task and modeling procedures reported by Powers (1989), Bourbon, Copeland, Dyer, Harman, and Mosley (1990), and Bourbon and Powers (1993). I describe them below. Predictions were run on 8 June 1988, at Stephen F. Austin State University, Nacogdoches, Texas. Predicted data were collected during a presentation at the annual meeting of the Control Systems Group, Durango, Colorado, on 31 July 1993.

The Subject and the Task

I was the subject. Figure 1A shows the experimental arrangement; Figure 1B shows the causal interactions among environmental variables; Figure 1C shows the results when I did one run of Condition 1 when no disturbance affected the cursor. The task was pursuit tracking. I used a control handle (*h*) to keep a cursor (*c*) aligned with a target (*t*)

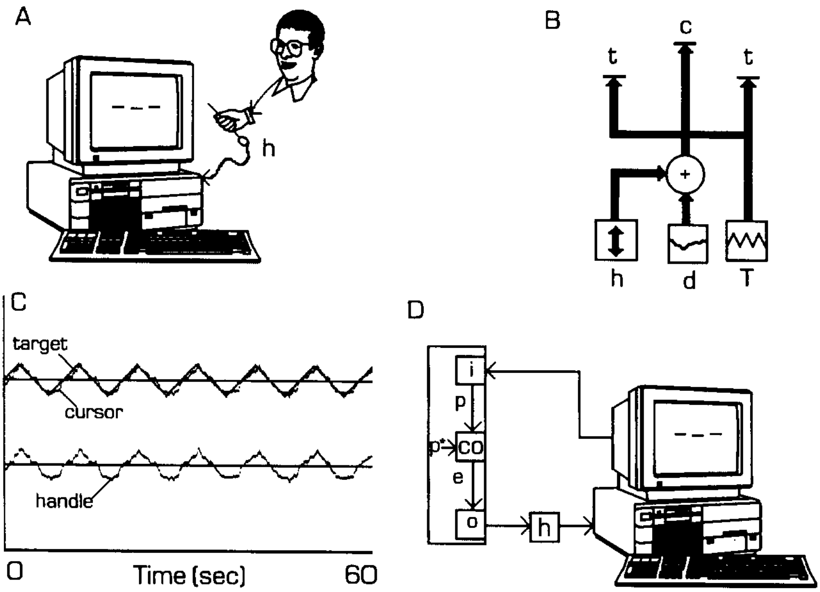

Figure 1. (A) The experimental arrangement; (B) causal interactions among environmental variables; (C) data from a 1-minute run of Condition 1 by the person; and (D) a representation of the PCT model of the person. (In the environment, h = control handle, d = disturbance, T = target function, t = target, and c = cursor; $t = T$, and $cur = h + d$. In the person's data, for target and cursor, "up" in the figure is toward the top of the computer screen; for the handle, "up' is away from the person. In the model, the functions are, i = input (sensor), co = comparison, and o = output; the signals are, p = perceptual signal, p^* = reference signal, and e = error signal.

comprising two marks on the computer screen. Every 1/30 sec during a run, the program (1) took new values of the target (T) and the random disturbance (d) from two time-indexed records created in 1988 at the start of Condition 1; (2) sampled the position of the handle and converted it to a value scaled to the height of the computer screen; and (3) plotted the cursor and target at new positions on the screen. The target marks always moved up and down synchronously at the same uniform rate between fixed limits. For the target, $t = T$; for the cursor, $c = h + d$. In 1988, d was zero; for each prediction of Condition 2, the program created and saved a different time-indexed record of random values for d.

The Model from Perceptual Control Theory

In a tracking task, a person acts on the environment to create and maintain (control) an intended relationship between the cursor and target. Perceptual control theorists assume that a person who controls during tracking, or any other situation, must (a) specify an intended perceived state of selected variables in the environment, (b) perceive the present state of the variables, (c) have the means to affect at least some of the perceived variables by acting on the environment, and (d) act so as to precisely cancel the effects of independent environmental influences that otherwise would make the present perception fail to match the intended one. A quantitative model of the person must duplicate all four of those processes.

Figure 1D shows the simplest PCT model that can duplicate a person's results in a tracking task. The model includes three functions (input function, i; comparison function, co; output function, o), and three signals (perceptual signal, p; reference signal, p^*; error signal, e). In the model, i operates on input quantities ("stimuli") from the environment, producing a momentary value of p (here p is the difference between positions of c and t; $p = c - t$). The reference signal, p^*, represents the person's intended perception. For each prediction in 1988, the program estimated p^* from the mean difference between the 1800 momentary positions of the cursor and target ($c - t$) during Condition 1. (The mean difference was zero pixels. A pixel is the minimum unit of vertical resolution on the screen.) To emulate the momentary relationship between the person's intended and actual perceptions, the model's comparator function co creates an error signal, e, by subtraction: $e = p - p^*$.

The output function, o, converts e into an output (a change, Δ, in the simulated position of the handle, h) that affects the cursor in the environment. In o, a constant of proportionality, k, represents how rapidly I moved the handle when e was non-zero. The output of the model is, $\Delta h = k \bullet e$; the model changes its output proportionally to, and in the opposite direction from, e. To estimate k, an arbitrary low value is inserted into the program steps for the model (shown below), the other variables in the model are initialized to their values at the first sampled interval of the person's run in Condition 1, and the model's program steps are iterated 1799 times, once for every sampling interval during a run by me. On each successive iteration, the newly calculated values of handle and cursor positions are substituted in the model, along with the next values of the target and disturbance. After 1799 steps, a new value of k is substituted and the iterative procedure is repeated. That process continues until the cursor positions produced by the model differ as little as possible from the ones produced by the person, with the difference assessed by a least-squared error procedure. The value of k that produces that best fit is used in all subsequent runs of the model for that task.

The program steps in an elemental PCT model form a system of two simultaneous equations, one for the environment and one for the organism. [For detailed discussions of the model, see Bourbon and

Powers (1993); Pavloski, Barron, & Hogue, 1990, pp. 33-37; Powers, 1973, pp. 273-282, 1978, pp. 422-428; and Runkel, 1990, pp. 93-99]. The equations, represented as computer program steps in the Turbo PASCAL programming language, are:

$c := h + d$ for the environment

and

$h := h - \Delta h$ (where $h - \Delta h := h - k \bullet e := h - k(p - p^*)$) for the person.

Those two program steps comprise the simplest functional PCT model.

Procedure: 1988-1993

Bourbon et al. (1990) described results when, in 1988, 10 people did 104 replications of the pursuit tracking task. In each replication, after Condition 1 (with no disturbance) we used the PCT model to predict results of Condition 2 (with a disturbance). For 100 runs, Condition 2 occurred a few minutes after the predictions; for the other 4 runs, 1 year elapsed before Condition 2. The participants controlled well: In Condition 1 the mean distance between cursor and target was -.3 pixels (SD = .6, N = 104 runs); in Condition 2 the mean distance was -.2 pixels (SD = .6, N = 104 runs).

Predictions by the PCT model were accurate and reliable. For the 100 runs when Condition 2 occurred within a few minutes of a prediction, the mean correlation between sets of 1800 predicted and actual handle positions was r = .996 (SD = .002, N = 100). In the four runs delayed for 1 year after the predictions, the mean correlation between predicted and actual handle positions was r = .996. Predictions by the PCT model held true after 1 year; would they for longer periods? In the present paper I report results from the first in a series of tests for predictions made in 1988, when we estimated p^* and k, the parameters of the PCT model, and used the model to predict results for eight runs of Condition 2. Two predicted runs will occur every 5 years for 20 years. In 1993, I did two predicted runs.

Results

Figure 2A shows the data for the first pair of predicted and actual runs; Figure 2B, for the second pair. In each figure, my own data and the data predicted by the PCT model for that run are plotted on the same coordinates. You may need to look closely to see any differences between the model's data and my own; many of our data points plot on top of one another. For data in Figure 2A, correlations between predicted and actual positions were, for the cursor, r = .971, and for the handle, r = .998. For the run in Figure 2B, correlations between predicted and actual positions were, for the cursor, r =.974, and for the handle, r = .997. By themselves, these correlations might merely indicate that high or low values in the predictions were more or less associated with similar values in my data, but that is not so; the predicted and actual values were strikingly similar. For the data shown in Figure 2A, the mean

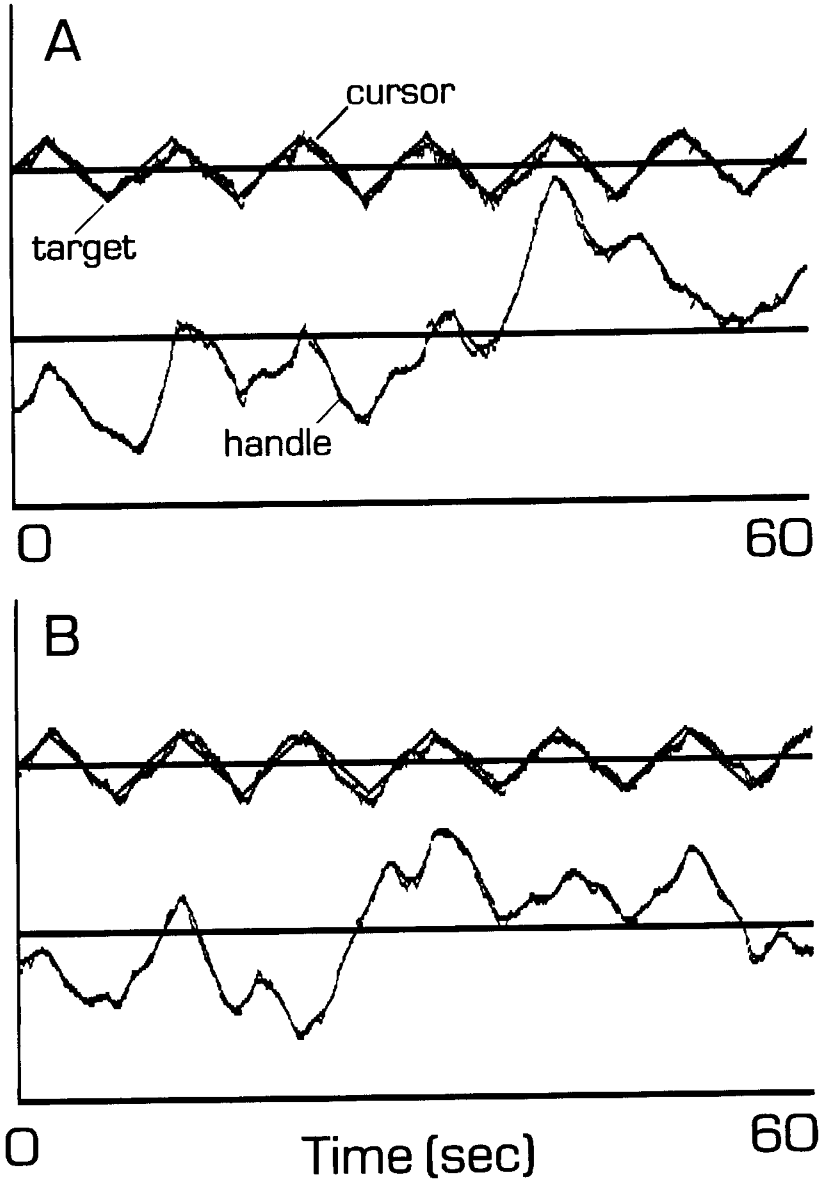

Figure 2. Predictions (in 1988) by the PCT model, and the person's results (in 1993), for two runs (A and B) of disturbed pursuit tracking. Data from the model and person are plotted on the same coordinates and are almost indistinguishable. (Positions of the handle, target, and cursor are depicted using the same conventions as in Figure 1.)

difference between predicted and actual handle positions, expressed in equivalent units of resolution on the computer screen, was -0.6 pixels (*SD* = 1.7, *N* = 1800 data pairs); for the data in Figure 2B, the mean difference was -0.9 pixels (*SD* = 1.5, *N* = 1800). Graphically, and in the descriptive statistics, the close agreement between predictions and actual data is obvious. No statistical test of significance is necessary to confirm that fact.

Discussion

In PCT, a person is modeled as a system that simultaneously and continuously (a) specifies an intended perception, (b) compares present perceptions against the intended one, and (c) varies its actions as necessary to eliminate differences between intended and actual perceptions. When we know the perception a person is controlling, as we did in the present examples, the PCT model predicts actions as accurately 5 years in advance as it does across a few minutes or a year.

A common misconception about procedures like those used here is that the behavior of one person could be substituted for that of another and the results would not change. It is true that the results for any two people who track at all well will be similar, but even seemingly small differences between them can be informative. To illustrate that point, I recalculated the prediction for my run shown in Figure 2A, but instead of using the value of k estimated from my own data in 1988, I substituted the value from another person. (In 1988, her movements were a little less rapid than mine.) The match between my data and the recalculated prediction was not quite as good as the original one. The handle movements of the revised model always lagged behind mine by a small amount and the standard deviation of the difference between predicted and actual handle positions increased from 1.7 pixels with my own value of k, to 2.4 with the new value. With my value, the correlation between predicted and actual handle positions was $r = .998$; with the substituted k, it was $r = .995$. A difference of .003 might seem small, but it would occur *every time* I substituted her value of k for my own. For idiographic predictions as precise and accurate as those reported here, differences in the third decimal place of a correlation coefficient can be highly reliable.

When we see a demonstration like the one shown here, it is tempting to think that everyone already knows past behavior is the best predictor of future behavior. That idea is correct, if we mean past successful *results* of a person's actions are good predictors of future successful results. Successful control in the past is a good predictor of successful control in the future, but when people control the same variables at different times, their actions necessarily vary. The best predictor of a person's *actions* in the future is not a knowledge of actions in the past. Instead, we predict best when we know the *perceived variables* a person controls; then we can predict the specific actions that will occur, given a particular disturbance applied to those variables. Incidentally, the fact that a person must vary his or her specific actions, in order to produce unvarying results on different occasions, rules out explanations that depend on a previously learned pattern or program of neural "commands" to tell the muscles how to make the same actions on each occasion.

Sometimes observers mistakenly interpret control as merely another example of eye-hand coordination. Granted that control entails coordination, there is still the question of how the eye and hand become coordinated and remain that way. Taken as an explanation, "eye-hand coordination" is a kind of radical reflexological theory that says environmental stimuli act on the eye and subsequently control behavior, but even in the simplest tracking task (not to mention instances of successful eating or driving), there is no independent antecedent stimulus to control behavior as a dependent variable. [For more on this subject, see the paper by Bourbon and Powers (1993)]. For example, the *target* might be an independent stimulus; my hand movements did approximate the target's trajectory during Condition 1, when there was no disturbance. However, in the disturbed conditions my hand did not match the target movements. The *disturbance* cannot be an independent controlling stimulus; I never saw it directly and my actions eliminated nearly all effects it otherwise would have had on the position of the cursor. Not even the *relationship* of the cursor and target can serve as an independent antecedent stimulus that acts on my eyes, which control my hand; at every moment, my own actions combine with the values of the disturbance and target to determine the distance between the cursor and target. Successful tracking, like successful control of any kind, is not created by the eye telling the hand what to do, but by the hand acting so that, through the eye, the person sees what he or she intends it to see.

When they try to explain control, people often suggest possible causal roles for traditional psychological constructs like knowledge, instructions, and experience: I know what I want to do and my knowledge determines the results; when we give instructions to a subject who then controls well, the instructions determine that the person does what we instruct; I am experienced at the task and my experience determines the results. Explanations like those all beg the question of *how* experience, instructions, or knowledge might cause a person to be an effective controller. The present demonstrations reveal a possible role for those constructs: they might pertain to the person's selection of intended perceptions. After the selection, the constructs play no further role in the phenomenon of control.

Conclusion

If you ask them, people often say that, when they act intentionally, they know what they want to see (perceive), they know what they see, they know they must act to make what they see match what they want to see, and they know whether their actions succeed. In PCT, the model for the person includes quantitative functions and signals that explicitly represent many of those commonsensical ideas about intentionality. When it comes to accurately predicting the positions of the control handle one day in 1998, and again in 2003 and 2008, if the choice is between traditional behavioral science or perceptual control theory, the sure bet is on common sense and PCT.

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