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# THE CAUSE OF CONTROL MOVEMENTS IN A TRACKING TASK

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*Summary.*—The classical cause-effect or input-output model of behavior breaks down when there is feedback from response to stimulus. Using a compensatory tracking task it is shown that response variations on different occasions can be nearly identical while stimulus variations on these occasions are completely unrelated. This result seems to rule out stimulus variations as the cause of responses which control (stabilize) the stimulus. When feedback exists, the cause of control must be viewed as an internal reference rather than an external stimulus.

In compensatory tracking tasks a subject is asked to control a cursor, keeping it aligned with a stationary target. To accomplish this the subject must make responses (for example, vary the position of a handle) to compensate for disturbances of the cursor's position. Much of the research on this task concerns the effects of temporal characteristics of disturbances on the accuracy of control of movements (1). This paper addresses a different question, namely, "How is this control effected?". The conventional answer is that some aspect of the stimulus (such as the position or rate of change in position of the cursor) is transformed into responses (handle positions) which control the cursor, keeping it stabilized near the target (3, 4, 8). Powers (5, 6) has taken pains to explain that, when there is feedback from response to stimulus, such that there is a *closed loop* of cause and effect, conventional explanations which treat stimulus as cause and response as effect are no longer appropriate. The feedback link between response and stimulus is physically explicit in the compensatory tracking task. The stimulus (cursor) is at any instant both a cause and an effect of the subject's responses. While researchers have noticed the existence of feedback in tracking and other tasks (such as operant conditioning), the behavior of the subject is still explained conventionally (2).

What seems to be needed is evidence that the conventional explanation of tracking behavior fails when feedback exists. Powers (6) has attempted to provide such evidence, showing that the correlation between response (handle position) and stimulus (cursor position) in a compensatory tracking task is typically less than .1 while that between response and disturbance is greater than .99. According to the conventional view, some property of the cursor must guide responses. However, variations of the cursor are apparently unrelated to responses while variations of the disturbance (which are visible only via their effects on the cursor) predict responses perfectly. According to Powers, when there is feedback from response to stimulus ". . . not only the

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old cause-effect model breaks down, the very basis of experimental psychology breaks down as well" (6).

Anyone who has watched a subject perform a compensatory tracking task would find it hard to believe that variations of the cursor have no determinable relationship to responses. What, besides the cursor itself, could tell the subject what response to make to keep the cursor aligned with the target? It seems that there must be *some* rule that will relate stimulus to response variations in these tasks. Rather than attempt to find this rule, an experiment was designed to test the possibility that any rule might be found relating stimulus to response when there is feedback. If such a rule exists, then stimulus variations on different occasions should be about the same if response variations on these occasions are nearly identical. It is a simple matter to produce responses that are similar on different occasions. Since responses are highly correlated with disturbances, creating the same disturbance twice will result in similar responses. If the conventional view is correct there should be a high correlation between variations of the cursor on these two occasions.

## METHOD

Three male subjects, two students and one faculty member at Augsburg College, were tested. All were experienced at performing compensatory tracking tasks.

The target and cursor were displayed on a video monitor controlled by an Apple II computer. Target and cursor were vertical lines, approximately 2 cm long, with the cursor immediately below the target. The horizontal position of the cursor was determined, at any instant (actually, every .1 sec.) by the sum of (a) the subject's response (a number corresponding to the angular position of the game paddle handle) and (b) the disturbance (a number generated by the computer). Temporal variations in the value of the disturbance were sinusoidal; frequencies ranged from .025 to .075 Hz on different experimental runs. The amplitude of the disturbance corresponded to 70% of the maximum possible horizontal deviation of the cursor from the target (about 10 cm).

Subjects were tested individually. Each subject was seated before the videodisplay and asked to keep the cursor aligned with the target by turning the game paddle handle appropriately. After several practice sessions subjects were tested in 20 experimental runs each lasting 30 sec. There was a 30-sec. rest between each run. The phase and frequency of the disturbance were determined randomly for each run. The same disturbance was repeated on pairs of nonconsecutive runs.

## RESULTS AND DISCUSSION

The results of interest are the correlations between variations of the cursor on pairs of runs with the same disturbance. An example of the results from one pair for one subject is shown in Fig. 1, top. The upper trace shows temporal variations in the position of the cursor during the last 20 sec. of one run. The lower trace shows temporal variations in the position of the cursor during the last 20 sec. of another run. The Pearson correlation between variations of the cursor on these two runs is .0032. Fig. 1, bottom, shows temporal variations in the response (the position of the game paddle handle) on the same two runs. The correlation between response variations is .997. The phase, amplitude and frequency (.037 Hz) of the disturbance were the same in both cases.

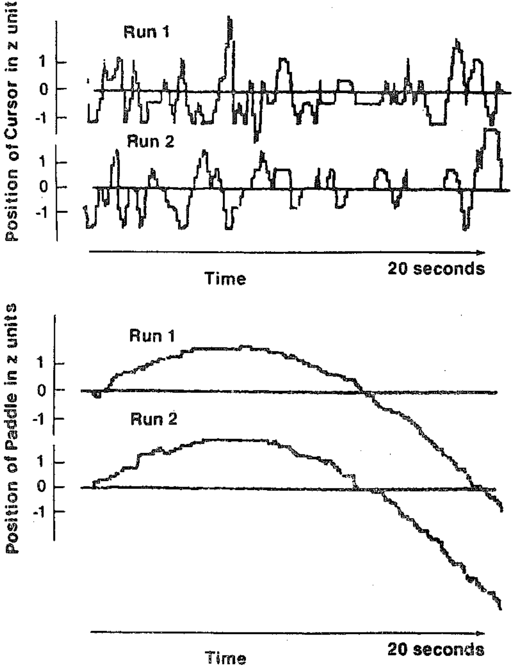

FIG. 1. Top: variations in the position of the cursor during the last 20 sec. of two different experimental runs with the same disturbance. Cursor position is expressed in units of the standard deviation of cursor variations from average cursor position on each run. Zero corresponds to the location of the target. Bottom: variations in the position of the game paddle handle during the last 20 sec. of the same two experimental runs shown above. Paddle position is expressed in units of the standard deviation of paddle variations from the average position of the paddle on each run. Zero corresponds to the position of the paddle which keeps the cursor aligned with the target when there is no disturbance acting on the cursor.

For all subjects, the correlation between variations of the cursor on any two runs with the same disturbance was usually less than .2 and rarely exceeded .6. The correlation between response variations on these runs was always greater than .99, often exceeding .998. These response correlations occurred for pairs of runs which were *not* consecutive. Thus, the subject could not produce these correlations by repeating from memory the responses made on the immediately prior run. Also, there was no way for the subject to know in advance which responses to make to control the cursor (keep it aligned with the target) on a particular run.

For all subjects, the average deviation of the cursor from the target on any run was less than 1% of the maximum possible deviation which could be produced by the disturbance. To achieve this level of control, responses had to be almost exactly opposite to disturbances. Producing the same disturbance on two occasions, therefore, results in highly similar responses (Fig. 1, bottom). However, what the subject actually sees on these two occasions may be completely different (top).

The data shown in Fig. 1 are rather surprising from the conventional perspective. Nearly the same response variations occur on two occasions in the absence of any congruity between stimulus variations on these occasions. The puzzling lack of correlation between variations of the cursor on different occasions results from looking at the cursor as the stimulus when, in fact, it is both stimulus and response. The problem arises from imagining it is possible to "break into" the closed loop of cause and effect and view one part of the loop as cause and another as effect when, in fact, each variable in the loop is both cause and effect at any instant.

The results of this experiment are not surprising from the point of view of control theory. In fact, a computer simulation of a single-level control system (7) produced results similar to those of the human subjects (a low correlation between variations of the cursor on different runs with the same disturbance). The only random element in the simulation was the starting position of the handle for the game paddle.

The cause of control (the almost perfectly stabilized position of the cursor) in this tracking task must be viewed as being inside the subject, not in the stimulus which is being controlled. This can be seen most clearly if the subject is asked to vary the position of the cursor in an arbitrary manner. The cursor will be controlled at different positions as evidenced by the fact that responses resist disturbances which would tend to move the cursor from these positions. The subject is acting as a control system with a varying internal reference for the position of the cursor. The internal reference, not the cursor itself, controls the position of the cursor. Powers (5) described a theory to account for the variations in internal references in living control systems.

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