an experiment, but afterward control moths returned at a greater rate than mimics. These authors overcame the problem by releasing small numbers of mimics in several areas so that predators would not have the opportunity to learn that they were edible. The results of the small-scale experiments confirmed that Batesian mimicry was functional when certain ecological parameters were satisfied.
14. Statistical tests were derived from S. Siegel, *Nonparametric Statistics for the Behavioral Sciences* (McGraw-Hill, New York, 1956) (Mann-Whitney U test) and R. R. Sokal and F. J. Rohlf, *Biometry, the Principles and Practice of Statistics in Biological Research* (Freeman, San Francisco, 1969) (G-statistic).
15. During 1968, experiments were carried out between 12 February and 9 June, with an additional census being made on 11 August. The 1969 experiments were conducted between 12 January and 14 April. This second set of experiments began 31 days earlier and was continued over 92 days versus 118 days for the intensive part of the sampling period in 1968.
16. R. R. Sokal and F. J. Rohlf, *Biometry, the Principles and Practice of Statistics in Biological Research* (Freeman, San Francisco, 1969), p. 623.
17. This report incorporates material from my Ph.D. thesis sponsored by the Department of Zoology, University of Washington. Financial support came from an NSF predoctoral fellowship and grant GB-6518X administered by the University of Washington. Logistic support by the Organization for Tropical Studies greatly facilitated field work. I acknowledge Dr. Gordon H. Orians for help at all stages of research and writing and Drs. Keith S. Brown, Jr., W. T. Edmondson, and John Edwards for commenting on the manuscript. Finally, Mr. Jorge Campabadal and Miss Liliana Echiverria of OTS have been particularly helpful in making feasible this research under what would otherwise have been difficult conditions.
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# Feedback: Real-Time Delayed Vision of One's Own Tracking Behavior

Abstract. *When a televised display of a person's own behavior in pursuit tracking is delayed, his performance, as measured by time on target, is seriously degraded. Data for six subjects on two tracking patterns under seven delay values reveal a linear inverse relationship between the logarithm of the time on target and the magnitude of delay.*

Over 10 years ago the first observations on the effects of delayed vision (520 msec) of one's own behavior via television were reported (*1*). Unforeseen technical difficulties made it impossible until now to extend those initial observations to the systematic study of delay values. Variable delays of a television picture in the range of milliseconds with video tape instrumentation proved impossible to achieve. Recently, however, by using a specially designed video disk recording and playback device (*2*), we have been able to store a televised display of a person's own behavior prior to playback for periods of 17 msec to 3 seconds in steps of approximately 30 msec. This technique of delaying visual feedback has important implications for studies in experimental psychology, developmental psychology, psychopharmacology, sensory psychology, and clinical neurology.

In order to study one aspect of the effects of various delay magnitudes on performance a rotary pursuit task (*3*) was used. The subject sat directly in front of a 58-cm television monitor with the center of the monitor 91 cm away and at eye level. The camera, placed just above the subject's head, pointed toward the task area. The subject could observe the tracking display, his hand, and his forearm on the monitor, but a special occluder prevented him from seeing directly the tracking device or his hand and forearm. The linear size of the tracking pattern on the monitor was approximately 5 percent smaller than the actual pattern. Two tracking patterns were used: a circle (20 cm in diameter) and an octagon (19 cm on a side) with four very short sides at what would have been the corners of a square. These patterns appeared on the monitor as dark gray on a light gray background. The moving target consisted of a bright illuminated patch (19-mm square) which followed the circular or octagonal path. Because of the nature of the tracking device, the moving target on the circular pattern traveled at a constant velocity of 120° per second but accelerated and decelerated around this value on the octagonal path.

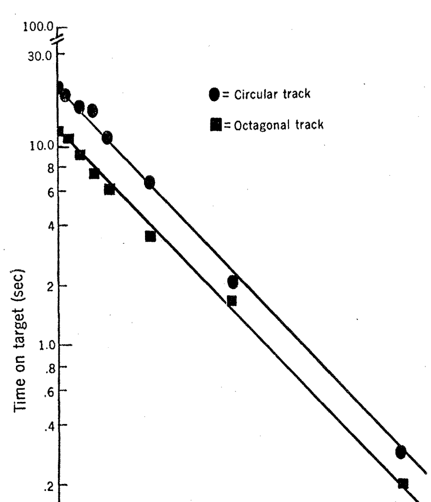


Fig. 1. Tracking performance for two tracking patterns under delayed vision. Each data point represents the mean time on target for six subjects under no delay and seven values of visual delay (17, 50, 80, 120, 220, 420, and 820 msec).

Each subject tracked the moving target with a wand having a photosensitive transducer in its tip. The measure of performance was total time on target for a 30-second trial period. Data were obtained for six subjects in each of seven delay conditions (17, 50, 80, 120, 220, 420, and 820 msec) and one no-delay condition. Target order was counterbalanced across subjects, and two trials were obtained from each subject on both tracking patterns for each of the eight viewing conditions. An up-and-down procedure was used in presenting the seven delay conditions and the no-delay condition.

The results are summarized in Fig. 1 and show an inverse linear relationship between log time on target and magnitude of delay. The lines in Fig. 1 are visually fitted to the data points. Transmission visual delays (*4*) of one's own tracking behavior clearly disturb performance, even with a delay as brief as 17 msec, a magnitude approximating the transmission time of visual information from eye to brain. Moreover, the degradation of performance becomes marked with a delay of 250 msec, the duration of a typical visual reaction time. At this value, performance on both tracking patterns is reduced by more than 60 percent of base-line, no-delay levels. With a delay of 420 msec, performance is approximately 16 and 10 percent of original no-delay levels for the circle and the octagonal patterns, respectively. The difference in difficulty between the two tracking patterns is evident from the data in Fig. 1. Figure 1 also shows that the variable velocity of the target for the octagonal tracking pattern had no differential effect on the nature of the relationship between magnitude of delay and performance. The large decrements in performance with increasing delay occurred despite the fact that the movement of the target followed a predictable path—one which was always visible. Individual differences in performance for both target courses were more marked for the no-delay condition and the first three delay values, the standard deviations ranging from 2.8 to 50 seconds. In general, the variability among subjects decreased for both target courses as delay magnitude increased.

These results on the effect of visual transmission delay of one's own pursuit tracking behavior are very similar to those of Warrick (*5*) on compensatory tracking with simulated transmission delay lags of 0 to 320 msec between hand control and a visual indication of the effects of control. Although Warrick's subjects did not have a direct delayed view of their own behavior, and despite the fact that their task was one of compensatory tracking with a complex oscillatory pattern, the relationship found between delay and performance (log time on target) was linear as in the present study, but with a different slope. In tracking behavior, at least, any transmission-type visual delay degrades performance —the larger the delay, the greater the effect—and this conclusion holds for both delay of a visual indicator (such as a pointer) of response and delay of the actual view of one's own response or behavior. In addition, the disturbing effects of delay do not appear to depend on the subject's ability to discern or perceive directly the temporal delay between the operation of a control and its resultant effects, or the delay between his movement and the visual perception of it. While in the present experiment this question was not investigated directly, reports of the subjects indicated that at the three shorter delay values (17, 50, and 80 msec) it was very difficult, if not impossible, to perceive or sense that there was a delay between their hand and arm movements and the visual perception of them. Warrick (*5*) reported similarly for delays of 60 msec or less.

In addition to these effects of delayed visual feedback on performance, a rather striking qualitative or subjective effect is worth noting briefly. When the visual delay is of the order of 250 msec (visual reaction time), one's arm and hand movements take on a peculiar "rubbery" quality in appearance and feel. At longer delays (such as 600 msec) this impression is lost. Whether this proprioceptive-visual interactive effect is transitory will require further study.

The newly developed video disk technology which made the present experiment possible portends important developments in research on visual feedback in relation to organization and control in visual-motor behavior.

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6. I thank T. Hines, W. Jack, and W. Neely for their assistance in this research.

18 February 1972; revised 6 April 1972

## Patterns in Productivity of Scientists

*Abstract.* *Bibliographies of 53 eminent research scientists in different fields are analyzed in terms of total publications, type of publication, coauthorship, and mean number of publications per year. For the physical and biological scientists, comparisons are made with the publication records of 153 eminent 19th-century scientists.*

In 1947 I began studies (*1*) of 64 leading American research men in the biological, physical, and social sciences, and I have continued in contact with most of them ever since; this contact included follow-up visits in 1963 (*2, 3*). Last year I was able to get current bibliographies from most of the men. Bibliographies of some who had died were available in the memoirs of the National Academy of Sciences. This report covers publications of 15 biologists, 17 physical scientists (experimental and theoretical) and 21 social

Table 1. Publications of 53 scientists of the 20th century (Exper., experimental; Theor., theoretical; Anthr., anthropologist; and Psychol., psychologists).

| Data | Biologists | Physical scientists | | | Social scientists | | |
|---|---|---|---|---|---|---|---|
| | | Exper. | Theor. | Both | Anthr. | Psychol. | Both |
| | | | *Scientists (No.)* | | | | |
| | 15 | 9 | 8 | 17 | 7 | 14 | 21 |
| | | | *Books 1 (No.)* | | | | |
| Mean | 2.2 | 1.2 | 3.3 | 2.2 | 4.1 | 4.9 | 4.7 |
| Range | 0–8 | 0–3 | 0–11 | 0–11 | 2–8 | 0–12 | 0–12 |
| | | | *Books 2 (No.)* | | | | |
| Mean | 2.8 | 1.3 | 3.6 | 2.4 | 6.0 | 6.1 | 6.1 |
| Range | 0–10 | 0–4 | 1–12 | 0–12 | 3–11 | 1–16 | 1–16 |
| | | | *Research reports (No.)* | | | | |
| Mean | 103.1 | 95.4 | 98.2 | 96.8 | 25.4 | 79.9 | 61.6 |
| Range | 38–198 | 24–199 | 9–247 | 9–247 | 12–50 | 23–201 | 12–201 |
| | | | *Other technical publications (No.)* | | | | |
| Mean | 31.6 | 24.7 | 22.8 | 23.7 | 35.6 | 45.6 | 42.3 |
| Range | 8–66 | 5–72 | 2–95 | 2–95 | 10–62 | 17–95 | 10–95 |
| | | | *Coauthors (%)* | | | | |
| Mean | 32 | 51 | 35 | 44 | 17 | 40 | 32 |
| Range | 0–86 | 24–86 | 0–65 | 0–86 | 0–32 | 9–70 | 0–70 |
| | | | *Book reviews (No.)* | | | | |
| Mean | 8.4 | 0.8 | 1.4 | 1.0 | 54.6 | 14.1 | 27.9 |
| Range | 0–35 | 0–3 | 0–6 | 0–6 | 5–167 | 0–77 | 0–167 |
| | | | *Publications per year (No.)* | | | | |
| Mean | 3.2 | 3.4 | 3.3 | 3.4 | 3.4 | 3.8 | 3.7 |
| Range | 1.1–7.3 | 1.7–7.4 | 0.8–8.6 | 0.8–8.6 | 1.7–5.4 | 1.4–6.4 | 1.4–6.4 |
| | | | *Weighted publications per year* | | | | |
| Mean | 3.6 | 3.7 | 4.1 | 3.9 | 4.1 | 4.9 | 4.6 |
| Range | 1.1–8.4 | 1.4–8.2 | 1.0–10.2 | 1.0–10.2 | 2.9–5.3 | 2.2–9.4 | 2.2–9.4 |
| | | | *Nontechnical publications (No.)* | | | | |
| Mean | 23.5 | 6.1 | 4.6* | 5.4† | 36.7 | 16.9 | 23.5 |
| Range | 0–79 | 0–23 | 0–22 | 0–23 | 10–77 | 2–46 | 2–77 |
| | | | *Total publications per year (No.)* | | | | |
| Mean | 3.6 | 3.6 | 2.6* | 3.2† | 4.2 | 4.2 | 4.2 |
| Range | 1.4–8.4 | 1.5–7.5 | 0.8–4.7 | 0.8–7.3 | 2.2–7.1 | 2.0–6.8 | 2.0–7.1 |
| | | | *Weighted total publications per year (No.)* | | | | |
| Mean | 4.3 | 3.9 | 3.4* | 3.7† | 5.6 | 5.4 | 5.4 |
| Range | 1.4–12.4 | 1.5–8.3 | 1.0–5.4 | 1.0–8.3 | 3.1–7.7 | 2.8–9.8 | 2.8–9.3 |

* $N = 7$. † $N = 16$.