Reports

Human Choice Reaction Time within and among Sense Modalities

Abstract. Human choice reaction time was studied as a function of sense modality and inter- versus intrasensory coding at three levels of stimulus strength. Unlike the case in earlier studies, stimulus strength was equated across sense modalities. Classical findings were supported for strength and modality; intersensory coding was superior to intrasensory coding.

Human reaction time (RT) bears functional relationships to a number of stimulus, organismic, and task variables (*1, 2*). Among the more universally accepted of these relationships are the following: (i) RT is inversely related to stimulus strength; (ii) RT is longer for visual stimuli than for tactual or auditory signals (*3*); and (iii) RT is directly related to stimulus uncertainty or information content (*4, 5*). Recently, exceptions have been found to the third relationship mentioned above, the suggestion being made that optimal stimulus-response pairing can reduce or eliminate the uncertainty effect (*6*). The universality of the second relationship has also been questioned on the grounds that cross-sensory comparisons have typically been made in the absence of any perceptual equation of the stimuli (*1*). One purpose of the present experiment, therefore, was to compare RT values for vision, audition, and touch, using stimuli equated for perceived strength. The influence of strength per se was explored concurrently.

A second aim of the study was to investigate a problem concerning the capability of the human organism to process information. It has been suggested that man's information-handling capacity is partially determined by the number of sense modalities serving as input channels (*7*). If this contention is valid, one would expect RT's to be lower when the discriminative stimuli in a choice situation are coded by modality than when they are coded by dimensions within a modality.

The visual stimuli were provided by a 40-watt lamp (*8*) viewed through a ½-inch-square aperture at 28 inches. A filter inserted in the aperture passed only those wavelengths above 600 $m\mu$, thus minimizing changes in hue resulting from intensity manipulation. The auditory stimulus was a 100-cy/sec tone produced by an oscillator and delivered through earphones. The tactual stimulus was generated by a vibrator unit built around a 6-volt d-c relay coil and utilizing 60-cy/sec a-c line current (*9*). A ½-inch button contactor was applied to an area just below the third joint of the index finger on the back of the left hand. The intensity of both visual and tactual stimuli was controlled by a variable transformer, that of the auditory signal by the volume control on the oscillator.

The procedure used to equate stimulus magnitudes was based upon that reported by Stevens (*10*). First, three perceptually equidistant tonal intensities were determined by using the bisection judgments of six subjects. These intensities turned out to be 55, 70, and 81.6 db, respectively. Next, subjects were required to make cross-sensory loudness matches for each tonal intensity; that is, they manipulated the intensity of the visual and tactual stimuli until these were perceptually matched to the reference loudness. Each subject made four matches at each intensity level of visual and tactual stimuli. The geometric mean judgments were 0.07, 0.89, and 4.06 ft-lam for the visual stimuli, and 20.09, 24.73, and 27.15 db above threshold for the tactual stimuli.

With these values, the following experiment was designed to determine the effects of sensory mode, stimulus magnitude, and inter- versus intrasensory coding on RT. Six subjects performed a three-choice RT task under all combinations of experimental variables (that is, three modes by three magnitudes by two codes) in counterbalanced order. The task of a subject was to respond as quickly and accurately as possible to the occurrence of any of three signals by pressing the appropriate response key. The assignment of keys (and hence fingers) to signals was consistent for individual subjects, but was varied across subjects to minimize the confounding of motor effects.

A trial consisted of the appearance of 30 signals (10 for each response key) at a rate of six per minute. All stimuli to which incorrect responses were given were inserted later in the sequence; hence, all RT's reflect correct responses. Each subject performed nine trials under each condition; the first seven were considered training trials and were not used to evaluate RT performance. In general, four trials were completed in each daily session.

The results are summarized in Table 1. It is apparent that the classical findings with respect to sensory mode and stimulus strength are upheld. The only deviation from strict agreement with the classical data finds the intermediate visual and tactual signals yielding RT's of duration equal to (rather than shorter than) those produced by the stimuli of lowest strength under intrasensory coding. In all probability this reflects an adaptation effect resulting from repeated presentation of the strongest signals; after such adaptation, intermediate signals tend to appear weaker than normal and may become confused with the weakest signals. The few errors which occurred bear out this explanation. An analysis of variance performed on the data indicated that both the mode and strength effects are statistically significant ($P < .01$).

Table 1. Summary of mean RT's for the major experimental conditions: W, weak; I, intermediate; S, strong.

Coding	Mean RT (sec) W	I	S
	Visual		
Intrasensory	0.56	0.56	0.48
Intersensory	.46	.43	.40
	Tactual		
Intrasensory	.52	.52	.44
Intersensory	.40	.37	.34
	Auditory		
Intrasensory	.46	.44	.38
Intersensory	.40	.33	.31

Instructions for preparing reports. Begin the report with an abstract of from 45 to 55 words. The abstract should *not* repeat phrases employed in the title. It should work with the title to give the reader a summary of the results presented in the report proper.

Type manuscripts double-spaced and submit one ribbon copy and one carbon copy.

Limit the report proper to the equivalent of 1200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to *one* 2-column figure (that is, a figure whose width equals two columns of text) or to *one* 2-column table or to *two* 1-column illustrations, which may consist of two figures or two tables or one of each.

For further details see "Suggestions to contributors" [*Science* **125**, 16 (1957)].

The findings with respect to coding appear similarly conclusive: intersensory coding yields significantly shorter RT's than intrasensory coding ($P < .01$). The objection may be raised that since confusions occurred in the intrasensory situation, the differences obtained may be attributable to discrimination difficulty. To resolve this question, an extension of the study was carried out in which two-choice, rather than three-choice, RT's were measured under both coding schemes. Intersensory coding was restricted to the middle intensity on all sense modalities. Intrasensory coding involved only the highest and lowest intensities, thereby reducing the difficulty of the intensity discrimination to a minimum. The results indicated overall shorter RT values under the two-choice than under the three-choice conditions, thus supporting the relationship of RT to number of alternatives suggested by Hick (*4*). However, the differences attributable to coding were still present at a high level of statistical significance ($P < .01$).

The conclusions to be drawn from this study are as follows: (i) the classical relationships between RT and stimulus strength, number, and sense modality are supported for stimuli equated in loudness across the senses and presented under conditions of inter- as well as intrasensory coding; (ii) all stimuli yield shorter RT's when involved in choices among sense modalities than when involved in choices among levels of the same modality.

WILLIAM C. HOWELL
JACK E. DONALDSON
Ohio State University, Columbus

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8. Such an incandescent lamp was used to permit the desired intensity manipulation; its incandescent time was 0.06 sec to 90 percent maximum luminance. It is doubtful that this delay had any marked effect upon RT, since values obtained were comparable to those typically reported with gas-filled lamps (for example, Mowbray, *6*).
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Evaluating Reflux and Drainage in Foam Fractionations

Abstract. Extreme care must be exercised in assigning an observed increase in enrichment to the beneficial effects of reflux or drainage, particularly in a single-solute system. The use of a system containing two or more solutes is recommended.

A recent publication (*1*) has emphasized quite correctly the beneficial effect to be expected from reflux in enhancing enrichment ratios obtained in foam fractionations. Unfortunately, the contribution of drainage is difficult to isolate from that of reflux (*1, 2*). For example, an early study yielded an enrichment of about 9-fold for methyl orange under conditions in which 3 ml of condensed foam were collected in 10 minutes (*3*). On the other hand, collection of 1 ml during a 30- to 40-minute interval gave an enrichment just under 90 (*4*). [The slow collection rate was made possible by substituting for the 24-cm Vigreaux column (*3*) an inverted 250-ml conical separatory funnel. The small amount of foam that survived to pass slowly into the collection vessel was not colored, and it had a gossamer appearance.] Under the circumstances, one might be inclined to attribute much of that increase to improved drainage. However, the contribution of reflux could not safely be assumed to have remained constant.

An examination of the results of a fractionation of two substances provides a means for better evaluating the contributions of reflux and drainage. Thus, if reflux were the overriding factor, one might expect not only the individual enrichment ratios to increase but also the quotient of the enrichment ratios. The chief factor operating to oppose such an increase in the quotient would be the usual tendency of a solute to be enriched to a greater extent when the foam is in contact with a more dilute solution.

In the earlier study (*3*), enrichment ratios of 5.4 and 4.1 were obtained for the 2- and 1-naphthoates, respectively, when each was present alone, giving a quotient of 1.3; for an initially equimolar mixture, the quotient was about 2. When this work was repeated with the separatory funnel to improve drainage, enrichment ratios of 70 and 40 were obtained for the pure compounds; for a mixture having the same initial concentrations of each substance, the enrichment ratios were 43 and 21, and the quotient was 2.0. These results emphasize that one must be extremely cautious in drawing conclusions about the contribution of a single factor, whether it be reflux or drainage, from the change in enrichment of a one-solute system. In addition, it illustrates how competition for the surface by two solutes in a mixture can lower the enrichment ratios of each. At the same time, it shows that competition for the surface, aided by limited reflux, did not increase the enrichment quotient for the mixture over that calculated from the single-solute systems. In this case, better drainage must have been the reason for the changes in enrichment observed for the single-solute systems.

L. B. ROGERS*
JOHN W. OLVER
Department of Chemistry and
Laboratory for Nuclear Science,
Massachusetts Institute of Technology,
Cambridge

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* Present address: Department of Chemistry, Purdue University, Lafayette, Ind.

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Irradiation of Bacterial Luciferase in vivo

Abstract. The fading of in vivo luminescence which is characteristically displayed by resting cell suspensions of the luminous bacteria *Photobacterium fischeri* is partly accounted for by a gradual loss of active luciferase. This luminescence is further diminished by exposure of such suspensions to gamma radiation, but the irradiated cells yield more, rather than less, active luciferase than do cells of the nonirradiated suspension. These and similar results with menadione-treated cells indicate that, while luciferase is gradually inactivated by its catalysis of light production, it can resist inactivation by radiation better than can some component of its supporting metabolism.

In 1954 one of us (*1*) demonstrated that the luminescence of resting cell suspensions of the luminous bacteria *Photobacterium fischeri* could be significantly depressed by doses of radiation as low as 500 rad. At about the same time, the enzymatic nature of bacterial luminescence was being proved by Strehler and co-workers (*2*) and