creases in direct proportion to the angular speed of the stimulus. Discrepancies result from variations in procedures and from nonrandom effects of major variables. A recent report (*4*) has presented a rationale for interpreting the discrepancies.

The Weber ratio provides a convenient measure by means of which velocity discriminations may be compared with other sensory discriminations and with performances in tracking and predicting. As indicated by Fig. 1 and the least squares solution, the best estimate of $\Delta\omega/\omega$ for an unspecified ω is 0.10. This value is of the same order of magnitude as the Weber ratio for a loudness of 100 db at 1000 cy/sec and for cutaneous pressure at 5 gm/mm^2 and for smell of rubber at 200 olfacties (*6*).

Speed of target motion seems to have the same effect on tracking error as it has on the differential threshold, that is, tracking error increases as a linear function of speed (*7*). In addition, the discrimination of a 10-percent difference in speed agrees with the error a tracker makes when he follows a target which moves at a constant speed but suddenly disappears (*8*). The Weber ratio is also clearly related to predictions of future positions of a moving object (*9*).

Research on tracking and predictive behavior indicates the need to consider the effects of parameters other than speed. It may be anticipated that $\Delta\omega/\omega$, like other Weber ratios, is approximately constant only within a restricted range of stimulus variation, and that the systematic effects of major variables other than speed will become apparent in future experiments. The present report serves to indicate the potential utility which may result from appropriate experimental analyses of the Weber ratio for visual discriminations of velocity.

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Complementation at the Maroon-like Eye-Color Locus of Drosophila melanogaster

Abstract. Two "allelic" *Drosophila melanogaster* mutants which are deficient in xanthine dehydrogenase can complement one another in heterozygotes. This complementation is due to the production of small amounts of xanthine dehydrogenase, enough of which is present to restore the normal eye color. However, not enough of the enzyme is present to produce normal amounts of the enzyme products, or to reduce the accumulation of the enzyme substrates to levels found in wild-type flies.

Many cases have now been reported in which "allelic" genes can complement each other in heterozygotes or in heterocaryons to produce a wild-type phenotype. Such complementation has been reported for some eye-color alleles in *Habrobrocon* (*1*) and for some wing mutants (*2*) and the bithorax cluster (*3*) in *Drosophila*. The data indicate that restoration of proteins is involved, since, in *Neurospora*, glutamic dehydrogenase is found in heterocaryons of allelic mutants lacking this enzyme (*4*), while a similar situation exists for allelic mutants lacking adenylsuccinase (*5*). This is a report of a similar phenomenon which we have found in *Drosophila melanogaster* between "allelic" mutants which lack xanthine dehydrogenase.

Mutants deficient in this enzyme comprise two loci, maroon-like eye-color (*ma-l*) (*6*) and rosy eye color (*ry*), which are located on the first and third chromosomes, respectively (*7*). As a result of the deficiency of xanthine dehydrogenase, *ma-l* and *ry* mutants accumulate the enzyme substrates (hypoxanthine and 2-amino-4-hydroxypteridine), and show no trace of the products (uric acid and isoxanthopterin) formed from these compounds (*8*). Xanthine dehydrogenase has been purified from wild-type flies by using charcoal, ammonium sulfate, and calcium phosphate gel, and no activity could be detected in purified extracts of the mutants (*9*). In this report we are concerned solely with the *ma-l* locus.

In general, the chromatographic methods followed those described by Hadorn and Mitchell (*10*) and others; the enzymatic techniques followed those described by Glassman and Mitchell (*9*). The amount of xanthine dehydrogenase in the various stocks was determined as follows: Flies were homogenized (40 mg/ml) in a Kontes "Duall" glass tissue grinder in 0.1*M* Tris buffer at *p*H 8. An amount of charcoal (Norite-A) equal to the weight of the flies used was added to remove inhibitors, and after 30 minutes the solution was centrifuged at 20,000*g* for 20 minutes. One milliliter of the supernatant was placed in the fluorometer cuvette with 0.02 ml of $10^{-3}M$ methylene blue and 0.05 ml of $5 \times 10^{-4}M$ 2-amino-4-hydroxypteridine. The increase in fluorescence due to the formation of isoxanthopterin was detected in a Turner model 110 fluorometer using a primary filter with principal transmission at 360, and a Turner 2A with a Farrand interference filter transmitting at 416 mμ for a secondary filter. The red eye pigment was estimated by measuring the fluorescence directly on the paper (*11*). The other compounds were estimated visually.

The locus involved in this investigation is on the right end of the X-chromosome between Beadex wing (Bx^s) and suppressor of forked bristle (*su-f*) (*12*). The mutants are *ma-l*, induced by x-rays by Oliver (*7*), and the bronzy allele of maroon-like eye color ($ma\text{-}l^{bz}$), originally called bronzy by M. O. Fahmy, who induced it with phenylalanine mustard (*13*). The "allelism" of these mutants is based on their biochemical similarity, on the lack of complete complementation, and on the fact that no crossovers were observed in approximately 5000 progeny (*12*). This number is low, however, and does not rule out the possibility that these mutants are psuedoallelic; indeed, because they are complementary one might expect

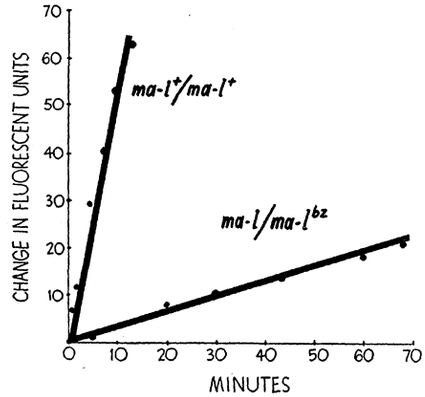

Fig. 1. Xanthine dehydrogenase activity in extracts of $ma\text{-}l^+/ma\text{-}l^+$ and $ma\text{-}l/ma\text{-}l^{bz}$. The assay was conducted as described in the text. It should be noted that no activity was detected in *ma-l* or $ma\text{-}l^{bz}$ flies.

that they will eventually be shown to cross over with each other.

The stocks used were vermilion eye color (*v*), forked bristle (*f*) Bx^3 *ma-l*, which was made from the *ma-l* strain at the California Institute of Technology, and *v* $ma\text{-}l^{bz}$, made from the bronzy (*bz*) stock kindly made available by Fahmy. The eye color of these stocks is yellow-orange; the presence of *v* facilitates their separation from the complementing flies (*v f* Bx^3 *ma-l*/*v* $ma\text{-}l^{bz}$) which have a bright red eye color. The wild-type stock used was an Oregon-R stock originally derived from the strain kept at Johns Hopkins University.

The results indicate that the phenotypes of *ma-l* and $ma\text{-}l^{bz}$ are similar (*12*). Both mutants have a diminution of the red pteridine components of the eye color and our investigation reveals that $ma\text{-}l^{bz}$, like *ma-l*, is deficient in xanthine dehydrogenase. There is a consequent absence of the enzyme's reaction products, while the enzyme's substrates accumulate. Both mutants are nonautonomous (*14*), and we have been able to show that both are maternally affected if their female parent contains $ma\text{-}l^{+}$ (*15*). However, it is of interest that neither *ma-l* nor $ma\text{-}l^{bz}$ is maternally affected if the mother was *ma-l*/$ma\text{-}l^{bz}$, a fact which indicates a functional relationship between these genes.

On the other hand, we find that females heterozygous for both genes (*ma-l*/$ma\text{-}l^{bz}$) have a normal eye color, indicating that the functional deficiencies of *ma-l* are not identical with those of $ma\text{-}l^{bz}$, and that one mutant can complement the functional losses of the other (*13*). This complementation, however, is not complete, since the amount of xanthine dehydrogenase present in *ma-l*/$ma\text{-}l^{bz}$ flies is only approximately 5 percent of that of the wild-type (Fig. 1); this small amount of enzyme is reflected by low amounts of uric acid and isoxanthopterin (the enzyme products) which we observe on paper chromatograms. The low enzyme level is further reflected in the fact that hypoxanthine, which is usually present in only trace amounts in wild-type flies, accumulates in *ma-l*/$ma\text{-}l^{bz}$ flies.

Other workers have also reported that the levels of enzyme found in complements are much lower than that found in the wild type (*4*, *5*). The general picture found in *ma-l*/$ma\text{-}l^{bz}$ flies resembles that found in maternally affected *ma-l* males in which relatively small amounts of enzyme restore the normal eye pigmentation while only a small effect is observed on the rest of the biochemicals involved (*15*). Why this should occur is not understood, since we do not know the reactions which lead to the formation of the red pigment. Nor do we understand the mechanism behind the complementation phenomenon, which presumably occurs as a "recombination of parts" of either the template or of the enzyme. Woodward (*16*) has reported in vitro complementation when mycelial extracts of mutants which give in vivo complementation are mixed, but attempts to repeat this with our system have been negative thus far (*17*).

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6. The symbols used in this paper are as follows [based on (*7*)]: Bx^3, Beadex wing; *f*, forked bristle; *ma-l*, maroon-like eye color; $ma\text{-}l^{bz}$, bronzy allele of maroon-like; $ma\text{-}l^{+}$, the wild-type allele of *ma-l; ry*, rosy eye color; *su-f*, suppressor of forked bristle; *v*, vermillion eye color.
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Analysis of Firing Patterns in Single Neurons

Abstract. The use of a high-speed digital computer for investigation of neural firing patterns is described. The high sensitivity of the method permits detection of stimulus-response relations buried in a background of spontaneous activity.

The firing pattern of a neuron in a sensory system is generally more complex than a simple all-or-none response that occurs shortly after the delivery of a stimulus. Frequently, neurons exhibit spontaneous firings, and the change of a stimulus parameter may simultaneously affect (i) the total firing rate and its distribution in time, (ii) the interspike intervals, and (iii) the latency between the stimulus and the first spike of a burst. Visual inspection of oscilloscopic displays is most appropriate for the detection of type (iii) pattern changes. The observer who relies on such limited response criteria selects a biased sample from the total population of neurons available for observation. A more representative sampling of the population can be obtained by broadening the response criteria with a more quantitative description of the total firing patterns.

Compilation of such results from single-unit data has usually involved tedious "hand and eye" measurement of strip-film records (*1*), although some schemes have been developed for automatic display of the repetition of very constant and simple patterns of firing (*2*). In the present study the TX-O (*3*), a fast, general-purpose digital computer with a flexible input-output system, was used for the analysis of more complex firing patterns.

The TX-O computer was programed to perform two complementary analyses of tape-recorded data. The results are presented as two displays: (i) a time histogram—a histogram of the distribution of action potentials in time relative to the instant of stimulus presentation (summed over many stimulus presentations), and (ii) an interval histogram—a histogram of the occurrence of various interspike intervals (that is, time intervals that separate two successive action potentials). A peak on a time histogram shows preferred time of firing relative to the stimulus; a peak on an interval histogram shows a preferred interval between firings.

Note that both of these analyses involve time averages and therefore yield a time average of the firing pattern rather than single sequences of unit events in the pattern. The second form of analysis, the interval histogram, is mathematically similar to the autocorrelation function for a time function that is a train of pulses. Thus a Fourier transform of the smoothed interval histogram is related to a power spectrum (power as a function of frequency) of the trains of the cell firings. (It would be interesting to examine the order in which the "bins" in each of the two histograms are filled. Unfortunately, the relatively small number of events that can be observed in an experiment of reasonable length makes these fractional analyses statistically impractical.)

In our processing system, neuronal spikes and stimulus pulses from tape are picked out by discriminators and