apical (distal) member of the pair of daughter cells is always smaller than the basal. It has denser protoplasmic contents and its walls tend to bulge outward slightly. At some distance back from the tip, when elongation has ceased, this cell produces a root hair. The other cell, which rarely may divide again, never produces a hair. In these genera, therefore, differentiation for this character occurs very early and the potencies of the cells are sharply limited almost from the beginning. In *Chloris* and *Sporobolus*, on the other hand, trichoblasts ordinarily do not appear, all the cells being essentially equal in size from the beginning and all being capable of producing root hairs. Some of the cells stain differently from others, and a differentiation of root hair cells may occasionally be observed before the hairs are formed. These plants evidently provide good material for a study of the factors controlling the differentiation of root hairs.

Summary.—Materials and methods are described, by the use of which it is possible to observe and measure the multiplication and growth of cells in living root meristems. This technique has been applied to the problems of the location of new cell walls, of "sliding growth," and of the differentiation of cells which are to form root hairs.

[1] R. G. Leavitt, *Proc. Boston Soc. Nat. Hist.*, **31**, 273–313 (1904).

QUANTITATIVE ANALYSIS OF THE INTERACTION OF INDIVIDUALS

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Up to the present time, no quantitative studies of human interaction have been undertaken, with the exception of observations by Dorothy Thomas and her co-workers on the behavior of children.[1] These studies were designed to develop an "index of personality" based on the percentage of total time spent by a child handling objects, interacting with people or playing alone. Only percentage figures were secured for interaction, and the authors were more interested in developing criteria for determining the reliability of observers.

This paper represents a preliminary account of quantitative results secured through the use of a crude recording apparatus, now being superseded by an accurate instrument. Although the investigation was primarily exploratory, it is believed that a discussion of the results obtained by use of the old instrument will be of interest as an indication of the possibilities of research in this field. It must be emphasized that the conclusions herein presented are entirely tentative. They must be tested by the use of accurate apparatus under laboratory conditions (using a one-way screen, etc.). This work is now in progress.

The present studies resulted from the development of operational methods for the description of the relations of individuals. These operations were evolved in the course of the analysis of material collected in field studies of communities. From the consideration of this material, a working definition of the class of phenomena was derived, which may be stated briefly as follows: Individuals are considered to be in interaction if the action of one individual is followed by the action of another individual. The full definition and a description of the analytic procedures are given elsewhere.[2] Here it is sufficient to point out that such an action is a manifest (hence observable) phenomenon, and may be made up of words, gestures, in general, of overt muscular activities. No distinction is made between kinds of actions.

In order to obtain a record of a sequence of actions manifested by individuals, it is necessary to use some kind of a time-recording apparatus. Accordingly, a simple device was improvised. A large wheel was fitted to the rubber roll of an old noiseless typewriter. A small electric motor drove this wheel by friction at a uniform rate of speed (15 inches to the minute). A roll of adding-machine paper, mounted on a brass frame, was fed through the roll to a take-up driven by another small motor. The take-up motor rewound the paper on a wooden roll and was arranged so that no pull was exerted on the paper coming through the typewriter. Thus, any influence on the speed due to the changing size of the upper roll was eliminated. An observer, seated at the typewriter, struck a designated key when the first individual acted, and when this action was ended by the action of the second individual, another key was struck. By the alternation of the two letters on the moving tape, a continuous record of a conversation could be secured. The length of time of each action was obtained by measuring from the top of the first letter to the top of the second. We thus obtained a series of durations of the actions of two individuals.

Observations were made only on two individuals at a time, due to the limitations of the machine. Other difficulties in recording, now eliminated in the new apparatus mentioned, were due to the inability to record those instances when two individuals talked at the same time. (In this case, individual B was recorded as ending A's actions, and then almost immediately A comes in again.) It was also impossible to mark where one individual fell silent in the midst of an action and began again when the other individual was not observed to manifest an action. Because of the lack of proper facilities for observation the observer had to be seated in the same room, with the subjects at a distance of eight to ten feet away. The effect of this situation was to a large degree minimized, due to the fact that the subjects were colleagues who had known each other for several years, and the conversations were those which would ordinarily have taken place. The same observer was used in all observations described in this paper. For this reason, the error due to the observer may be regarded as constant, and is neglected in the rough approximations here described. We shall consider two series of eight observations, and one of five. One individual was a member of all three pairs. Due to difficulties in getting the subjects together, only a few observations were obtained on pairs made up of the other three individuals, and we shall therefore disregard those figures.

In each observation, lasting from thirty to fifty minutes, the two individuals manifested a total number of actions ranging from 320 actions (155 interactions) to 840 actions (420 interactions). The durations of any single action varied from 0.2 seconds (the minimum that could be recorded on the machine) to extreme values of well over a minute. Frequency distributions showed a characteristic asymmetry, the curve being definitely J-shaped. When one-second intervals were used, the mode fell in the interval between 0.2 and 1.1 seconds, containing about one-third of all values. The means of different individuals differ from observation to observation, the lowest 2.83, the highest 7.81, but approximately two-thirds of the values were found between the mean and 0.2, the other one-third in the higher values. In the present paper, we shall concern ourselves not with the probability that any single unit of action will have a given duration, but rather with the way in which the sequence of durations is arranged.

In order to describe the order of occurrence of the action-durations of two individuals, we obtained a kind of internal average by summing each five units of action. For reasons that need not be discussed here, attempts to use running averages were discarded. This summing of five should average out errors due to the observer; it is sufficiently small to be sensitive to fluctuations, yet at the same time affords the advantages of an average while enabling us to obtain the sum of the durations of any given series of actions. By comparison of the variation of the values of both individuals, A and B, we could begin to estimate the effect of one on the other. A visual representation was afforded by plotting the sequence of sums of fives for each individual on a graph, the ordinate representing the cumulative number of actions and the abscissa the cumulative time (sum of five) of the actions of each person. The same procedure was used in treating the units of interaction, summing by fives and plotting the results cumulatively.

Upon inspection of the curves for the separate individuals, it was seen that no single empirical function described all the curves in a single series of observations. We therefore provisionally regarded the curves as made up of a series of straight lines, each describing that period of action during which an individual's rate was approximately constant. By selecting points on the curve in which the variation was a minimum, we calculated the slopes between the points and thus obtained a sequence of slopes for each individual. The rate of any individual for a given slope is defined by $\Sigma t/n$.

It should be pointed out that in the present study we have to regard these slopes as making up a sequence of rates of silence for each individual. This way of looking at the facts derives from the operations used to obtain the discrete durations. With the particular apparatus used, a typewriter with a moving tape, we are unable to obtain a measure of the duration of an action of one individual uninterrupted by the action of the other individual. Let us suppose that one individual is observed to act continuously without pause for twenty seconds. If the other person acts by nodding his head or uttering a monosyllable, this single action would be recorded as made up of three or four shorter actions. On the other hand, if one individual remains silent while the other individual continues to talk, the silent individual obviously cannot be interrupted. His silence will continue until he manifests an action. In other words, with this machine we could not distinguish the pauses an individual makes in an action during which the other person acts from those instances when both were talking at the same time. If the reader wishes to regard these figures as representing rates of action, he merely needs to shift the figures about. It should be pointed out, however, that this way of regarding the figures is not justified by the operations, and the results obtained (now to be described) reinforce this view.

In table 1, we present the slopes (mean rate), the sum of the durations, as well as the durations of each slope in chronological time for two conversations from different series. The table is arranged in order of the occurrence of these slopes in the sequence of units of interaction. From this table, it may be seen how one individual often maintains a slope while the other changes several times. There is no simple relation between the durations and the values of the slopes; nor is there any evident correlation between the slopes of one individual and the other.

In order to obtain an approximate description of the interaction of individuals represented by these slopes, we shall have to consider three questions: (1) what determines the value of the slope of an individual; (2) what determines the duration of any single slope of an individual; and (3) what is the nature of the dependence of the individuals upon each other; that is, is this relationship expressed in the associated slopes and their durations?

Let us first take up the question of the relationship of these slopes to one another. It is evident that we cannot express a single slope of individual *A* as a function of the slope of individual *B*, since we do not find

TABLE 1

SLOPES AND DURATIONS OF SLOPES IN TWO EVENTS

Observation No. 37

NUMBER OF ACTIONS IN SLOPE	*EDC* SLOPE	SUM OF *EDC*'S ACTION PER SLOPE	DURATIONS OF *EDC*'S SLOPE	*GB*'S SLOPE	SUM OF TIME *GB*'S ACTION PER SLOPE	DURATION OF *GB*'S SLOPE
0–10	6.11	61.1	93.5	3.65	54.7	131.4
10–15	2.49	62.3	437.6	--	--	--
15–25	--	--	--	29.01	290.1	318.4
25–35	--	--	--	6.17	339.1	761.3
35–55	9.69	193.9	303.8	--	--	--
55–70	3.68	55.2	157.7	--	--	--
70–75	21.66	108.4	132.1	--	--	--
75–80	7.73	773.0	1345.3	--	--	--
80–115	--	--	--	2.78	97.2	393.0
115–160	--	--	--	4.75	213.7	566.8
160–175	--	--	--	14.76	221.4	291.1

Observation No. 29

NUMBER OF ACTIONS IN SLOPE	*EDC* SLOPE	SUM OF *EDC*'S ACTION PER SLOPE	DURATIONS OF *EDC*'S SLOPE	*CMA*'S SLOPE	SUM OF TIME *CMA*'S ACTION PER SLOPE	DURATION OF *CMA*'S SLOPE
0–30	3.15	94.5	166.6	2.57	128.4	257.9
30–50	1.96	78.3	229.6	--	--	--
50–70	--	--	--	3.47	243.6	414.7
70–85	3.71	55.7	90.2	--	--	--
85–105	1.06	21.1	83.8	--	--	--
105–120	3.65	292.2	559.1	--	--	--
120–150	--	--	--	2.22	66.7	188.9
150–155	--	--	--	10.84	54.2	72.5
155–180	--	--	--	2.50	62.5	143.7
180–185	--	--	--	9.06	90.6	113.9
185–190	2.84	298.7	612.1	--	--	--
190–240	--	--	--	2.06	103.1	282.4
240–290	--	--	--	3.04	151.8	267.4

NOTE: The broken line, --, indicates that the above slope continues. It should be noted that *EDC* is characterized by a pattern made up of a slow slope followed by a fast one, a simple alternation, while *GB* has wide variations due to two very slow slopes, and *CMA* exhibits a fast-slow pattern but with intermediate pairs of values having a different ratio than the first and last pairs exhibited.

one slope of individual *A* associated solely with a single slope of individual *B*. In fact, such a situation is very rare in this material (five times in 333 slopes manifested); while one individual maintains a constant rate, the other individual may manifest as many as five different slopes. If we hope to describe the duration of a single slope of individual A as some function of the slopes that B manifests during the time that A is constant we shall have to express the relationship as one between the durations. By estimating the ratio of the durations of A's slope to the total time (the sum of the durations of the slopes of both A and B), we can then see whether this varies as a function of the value of the slope.

When log slope is plotted as a function of this ratio for all the slopes manifested by one individual in interaction with another individual, it is found that the points representing the relationship make up a band. The band has a constant width and may be enclosed by two parallel lines

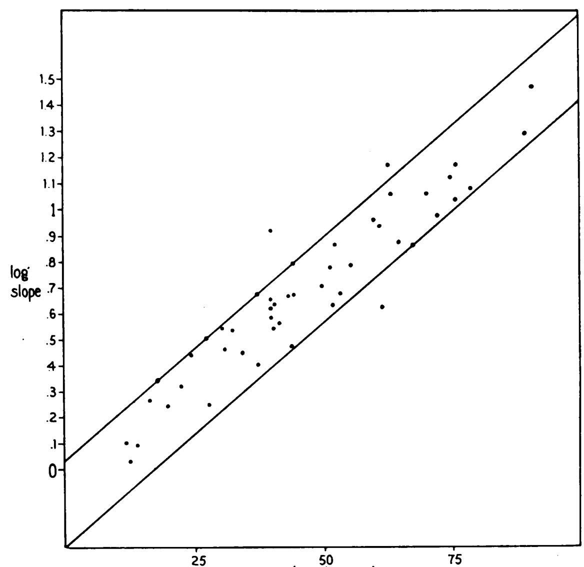

FIGURE 1

fitted to the points making up the border. Figure 1 represents the band of *GB* with *EDC*.

When the bands for the three pairs discussed here were plotted, it was found in the equation

$$\log S_A = k(t_A/t_A + t_B) + \text{constant}$$

where S equals the slope, and A and B are the two individuals, and t the sum of the durations, that the constant describing the slope of the band was the same for individual *EDC* in the three pairs in which he interacted, differing in slope from the bands of *GB*, *CMA* and *FLWR*, who also differed from each other. Unfortunately we were unable to obtain a sufficient series for the other individuals with each other, but it is an obvious possibility that the constant k in this relationship is invariant for each individual. This similarity in the value indicates why these slopes should be regarded as representing silences. Since the same slope is found for the silences and not for the individual's actions in three separate series, it may be assumed either that the individual adapts the durations of his actions to the other person and does not adapt his silences, or that the recording device's limitations are responsible. No solution is possible, of course, until a more accurate apparatus is employed.

What precisely does the band function tell us? In the first place, it is evident that the function imposes limits upon the duration of any single slope. If individual A manifests a slope of a particular value, and B manifests a slope which does not bring the value of the ratio within the limits of the band at the given value of log slope for A, then individual A will maintain this slope, until other slopes manifested by B bring the ratio within the band limits. Thus, the duration of a slope at a given value is determined (within certain limits) by the proportion it makes with the total time. For the different individuals with whom *EDC* interacts, however, the band for the function has a different width, and it is suggested that the width of the band and the distribution of points within it is a measure of the degree of adaptation of the individuals to one another.

Not only do individuals seem to possess constant slopes with bands having definable limits; in one case, an individual, *FLWR*, exhibits a marked discontinuity. At a value of log 0.4800, the whole band shifts towards the X-axis and changes its slope, although the width of the band remains constant. This indicates, for this individual at least, that when he slows down to rates of silence above 3.02 seconds, the duration of his slope forms a greater proportion of the total time, and he has, therefore, differing rates of adjustment in interaction.

It should be pointed out that the limits of these bands cannot properly be regarded as defining the probability that repeated measurements of log slope as a function of the ratio will fall within the band instead of outside it. We shall come upon such a function a little later in this paper. In this case, however, the situation is more complex. If a band encloses the values of the function for each conversation, it will be observed that the width varies from day to day, although the slope remains constant. In some observations, all the points fall on a straight line; in others, points forming both borders of the total band are included in a single observation. The question of probability, then, involves the distribution of the variation for single observations. The limits of the band for all observations on a given pair define this probability. The view that the probability distribution is made up of bands for single observations is supported by the fact that the limits of the band do not act as limits which rigidly control the change of slope. That is, when individual A changes to a certain slope, the first slope of individual B may bring the ratio within the band limits. That individual A does not shift depends upon two factors, (1) the existence of minimum and possibly maximum durations for slopes, the former giving a kind of threshold effect, the conditions for which have not yet been investigated; and (2) the limits of variability defined by the width of the band in a single observation. In this latter case, the variation in width of the bands is an expression of the variation in adjustment of the slopes of one individual to the slopes of the other, and hence depends upon the variability of the constituent individuals.

If we are to investigate this variability further, we must develop some way of dealing with the individual values of the slopes, regarding the preliminary definition of the problem of their durations as sufficient for our present purposes. In one-half of all observations, 13 out of 23 for *EDC* of which seven were with *CMA*, and a smaller number for the other individuals, the sequence of slopes forms a pattern of alternating fast and slow slopes. In the majority of these cases, there is a constant relationship between the fast and slow slopes. That is, if each sequence is broken up into a series of pairs, and each slow slope in a pair divided by its accompanying fast slope, the ratio or its first difference is constant for all pairs in the observation. The constant varies from observation to observation. If we assume provisionally that this alternation of fast and slow slopes is characteristic of individuals in interaction, we must then try to show why deviations from this pattern take place. We shall not attempt to determine the conditions defining the ratios of the slopes nor the variation in their absolute values when the ratios are constant.

If a consistent explanation is to be introduced to explain the deviations, we must find out whether the variability in the values of slopes differs for each individual or whether all the individuals under consideration vary in the same way. In order to obtain a measure of this variability, the dispersion of the slopes was expressed as a function of their mean value. If log σ slope is plotted as a function of log Mean slope, where $\sigma = \sqrt{\Sigma x^2/n - 1}$, the measurements for all four individuals fall within the limits of a narrow band defining the probability that measurements of σ as a function of the Mean will fall within the band instead of outside it.[3] The slope is greater than one and the origin is on the abscissa. Hence $\log \sigma = k \log M + \text{Constant}$. It should be pointed out that a plot of σ of the raw figures against the Mean of the raw figures gives us a similar band with the slope approaching 1. It is, of course, premature to suppose that this function will be characteristic of all individuals on the basis of such a small sample, but it is of interest to point out that similar results have been obtained by Crozier and his co-workers for a wide variety of biological material.[4]

Since we know that these four individuals vary in exactly the same way, we do not have to regard the occurrence of extreme slopes for any single individual as due to a special property of that individual. Rather this variation or the causes thereof would seem to be common to all the individuals studied. If we assume that every individual alternates between fast and slow rates, then deviations from this pattern must have a consistent explanation. These deviations are uniformly very slow rates occurring either in a position where a slow rate was expected, but not one so large (on the theory that in any conversation, if the ratio of each fast slope to its accompanying slow slope is calculated, the constant derived is constant for all such pairs in a single conversation) or else such deviations occur in place of a fast slope, thus disturbing the regularity of the pattern. If the rates and durations of the other individual are then examined to see whether such deviations are preceded by uniform conditions, it is seen that in all cases the other individual has maintained a single slope for high numbers of interactions (from 30–100 units, the number varying with each individual). If it be remembered that the duration of a slope is determined (within limits) by the ratio of its duration to the total duration (sum of both A's and B's slopes during that time), then it is evident that deviations from the fast-slow pattern follow after a slope has been maintained *longer* than would have been the case if the rates of the two individuals had adapted to one another. This adaptation is, of course, determined by the value of the function, log slope $= k(t_A/t_A + t_B) +$ constant, for the constituent individuals.

Summary.—In recording the interaction of pairs of individuals, the measurements secured represent the durations of the separate actions of an individual alternated with his silences or inactions. If each five actions of an individual are summed and plotted cumulatively, a series of slopes is obtained, during each of which the individual maintains an approximately constant rate.

The analysis of these slopes indicates that the duration of each slope is determined by the rate of the slope and its duration in chronological time (the sum of the durations of both A and B), the relationship having the form, log slope $= k(t_A/t_A + t_B) +$ constant, within the limits of a band of constant width. It is suggested that the constant is invariant for the individual.

Each individual is regarded as alternating between fast and slow rates. Although the values of these rates vary in a single conversation, the ratio of each fast rate to its accompanying slow rate is constant for the conversation, but varies from event to event.

Deviations from this pattern occur in more than half the cases. It is shown, however, that both representatives of the pattern (calculated) and its deviations vary in a uniform way. If the mean of the slopes of each

conversation is calculated and its standard deviation, it is found that log σ slope $= k$(log Mean slope) + constant, with all the points falling within a band of constant width. This relationship was the same for all observations on four individuals. It was then assumed that deviations could not be due to individual differences in variability as measured by this function.

It was then shown that deviations were in all cases preceded by slopes maintained over a period of time due to the operation of the suggested uniformity governing the duration of slopes at different values.

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ASTROPHYSICAL CONSEQUENCES OF METASTABLE LEVELS IN HYDROGEN AND HELIUM

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1. The metastability of an atomic level can influence its population only under conditions which differ materially from thermodynamic equilibrium. In or near equilibrium the populations of the levels are independent of transition probabilities and depend only upon the temperature of the system. On the other hand, when the deviations from equilibrium are marked, as, for example, in the case of a gas excited by diluted black-body radiation (nebulae, outer shells of stars), cyclical processes play a fundamental rôle. Observationally the metastability of a level produces discernible effects when the interval of time between successive excitations is less than the lifetime of the level. Under these conditions, the metastable level can have a population of the same order of magnitude as in the case of equilibrium. Consequently, we may expect to observe in the continuous spectra of stars shining through the gas absorption lines arising from metastable levels, in addition to those arising from the ground level. Of course, for sufficiently great thicknesses of the gas we may observe weak absorption lines even when the metastability is not completely effective, provided that the number of atoms in the level is greater than about 10^{12} in a column whose cross-section is 1 cm.^{2} along the line of sight.

The existence of metastable levels in hydrogen (2S) and helium (2^1S