The Study of Velocity

by

John B. Calhoun
Center for Advanced Study in the Behavioral Sciences
202 Junipero Serra Boulevard
Stanford, California (to July 31, 1963)

and

Laboratory of Psychology
National Institute of Mental Health
Bethesda 14, Maryland

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(This is an informal discussion of a concept
and means of investigating it.)

Table and Figures at end of text
# Table of Contents

1. General Definition  ........................................ 1  
2. Empirical Measurement  ...................................... 2  
3. Statistical tests of significance  ......................... 5  
4. Experimental determination of optimal group size  ... 6  
5. Calculation of relative velocities  ....................... 11  
6. Optimal and actual group sizes  .......................... 13  
7. "Social temperature"  ...................................... 14  
8. The "Social Frost Zone" and psychotic-like disorders ... 17  
9. Smaller than optimal sized groups  ....................... 21  
10. Relevance to phenomena on the human level .......... 23  
11. General remarks concerning the experimental study of velocity 29  
12. The rationale for construction of an experimental enclosure 33  
13. A condensed velocity pen for mice  ..................... 35  
14. Initiation of a study of velocity  ........................ 39  
15. Marking for visual identification at a distance ........ 41  
16. Vitamin A and tranquilizers  .............................. 42  

Appendix  ................................................................ 47  
Tables  ..................................................................... 49  
Figures  ..................................................................... 56
1. General Definition

Velocity is a theoretical construct reflecting the degree of social withdrawal. The full details of this concept have been given in a paper by me titled "The Social Use of Space", and submitted for publication. However, since several persons have expressed interest in initiating studies of velocity I have prepared this summary of concepts and methods. For the sake of brevity, proof of the equations given here is omitted.

In any group there exists an ideal pattern of behavior and appearance. The more an individual deviates from this ideal the more restraints will be imposed upon him by his associates. And the more restraints an individual receives the more he will withdraw from social interaction. This withdrawal may be most precisely recognized in the reduction of the amount of time an individual spends in that portion of the field where most social interactions occur.
2. Empirical Measurement

Empirically velocity may be represented by a measure of the amount of time an animal spends in the center of a field so constructed as to bias social interactions taking place there. Let \( \theta \) represent such estimates of velocity.

Now given a field containing \( N \) animals, how do we obtain \( \theta \)? Assume we are dealing with a species with a clear day-night cycle of activity. Adjust the light cycle in the experimental setting so that the 12 hours of maximal activity of the animals will coincide with the normal wakeful period of the observer. If the animal studied is normally nocturnal as are so many rodents the lights in the experimental field should be placed on a cycle of dim light from 1000 to 2200 and bright from 2200 to 1000.

Now, with all animals marked for observation at a distance, observations may be scheduled as follows:

Establish four two-hour periods of observation

\[
\begin{align*}
0900 & - 1100 \\
1300 & - 1500 \\
1700 & - 1900 \\
2100 & - 2300
\end{align*}
\]

For minimum experimental purposes two groups will be compared. Call these A and B. Observations of the two groups may be made nearly simultaneously. Consider the first two-hour period.

Times of initiating observation

\[
\begin{align*}
\text{In A} & & \text{In B} \\
0900 & & 0915 \\
0930 & & 0945 \\
1000 & & 1015 \\
1030 & & 1045
\end{align*}
\]
The other three two-hour periods are treated similarly.

This means that each observation period lasts 15 minutes. Each animal which emerges out into the field, for however short a time, is given a score of one. If it returns to the peripheral areas of retreat and again returns to the field, it gets no further score. A single score simply means having been active in the field sometime during the fifteen-minute period of observation. Since there are 16 fifteen-minute periods the maximum rating is 16.

Repeat these observations twice more at not less than two weeks between observing and not more than six. \( \hat{v} \) will be the sum of the scores for these three periods of observation. Thus \( \hat{v} \) maximum is 48. Preferably a duplicate set of observations should be made by a second observer within three days of the first. When this is done \( \hat{v} \) becomes the mean of the sums obtained by the two observers. Where it is impossible for a second observer to participate, the lone observer can repeat his observations within three days. Scheduling observations in this way permits determination of stability of velocity subscores over time (i.e., between Periods 1, 2 and 3), as well as within periods, whether or not one or two observers are used.

In practice scoring is facilitated by listing the code numbers of the pelage marks for the \( N \) animals down the left side of a sheet. Then make 16 columns down the page. Each column represents a fifteen-minute period. Insert a symbol opposite each animal for each fifteen-minute period it is observed. This symbol may simply represent presence. However, it is very easy to supplement the symbol to indicate types of activities engaged in.
Occasionally an animal will go to sleep in the center of the field rather than returning to the usual peripheral place of retreat. When this happens, and if the animal sleeps through the entire fifteen-minute period it is not to be given a score.
3. Statistical tests of significance

Having completed observations for three periods a measure is available for each animal. Prepare a rank-order table with \( R_1 \), the first ranked animal, being the one with the largest \( \hat{v} \); and with \( R_n \), the nth ranked animal, being the animal with the lowest \( \hat{v} \).

On arithmetic paper let the abscissa be rank, \( R \), and the ordinate be velocity, \( \hat{v} \). Plot the observed points. They should approximate a straight line whose expected values may be calculated by the following equation, when \( v_R \) represents the expected velocity of any \( R \)th ranked individual.

\[
v_R = \left[ \frac{(N-R) + 1}{N} \right] \left[ \frac{2 \sum N \hat{v}_R}{N+1} \right]
\]

(1)

A chi square test of the difference between observed and expected:

\[
\chi^2 = \sum \left[ \frac{(\hat{v}_R - v_R)^2}{v_R} \right] \]

(2)

where \( \chi^2 \) has \( N-1 \) degrees of freedom.
4. Experimental determination of optimal group size

Equation (1) may be expected to produce close approximations of $v_R$ to $\hat{v}$ when the group being studied is of an optimal size with reference to the genetic constitution of the animals and the physical structure of the environment as this affects probability of contacts between individuals.

Regardless of whether one is treating velocity as a dependent or independent variable, one may find it desirable to determine what the optimal group size may be. This is of particular importance when contrasting two genetic strains of the same species in a given type of experiment field. For one sized and structured field the optimal group size for one strain may be 12, but for some other strain it may be as low as 8 or as high as 16. One should know this because valuation of results can best be made against a background of knowledge of how much in harmony are group size and environmental size and structure.

The optimal group size, $N_0$, can be determined, but only from the study of a larger than optimal sized group. This determination is possible from the empirical observation that there is a minimum level of velocity, below which the nth ranked animal can make no reductions without so stressing its physiology as to lead to its death. This minimum velocity is that which would characterize the nth ranked, omega, individual in an optimal sized group.

When the group size increases above the optimal level the velocity of the alpha ranked animal, who receives considerable restraints due to the excessive group size, has his velocity reduced below that
anticipated from Equation (1).

Let

\[ N_o = \text{optimal group size} \]

\[ v_n^{(r)} = \text{the relative velocity of the } n\text{th ranked omega individual} \]

\[ v_{\alpha}^{(r)} = \text{the relative velocity of the 1st ranked, alpha, individual} \]

What I have said above is that where

\[ N > N_o \]

\[ v_n^{(r)} = \frac{1}{N_o} \]  \hspace{1cm} (3)

in relative terms.

But

\[ v_{\alpha}^{(r)} = \frac{N}{N_o} \]  \hspace{1cm} (4)

only when \( N = N_o \); then \( v_{\alpha}^{(r)} = 1.0 \).

These \( v_n^{(r)} \) are relative velocities in which that of the alpha individual in an \( N_o \) group is 1.0 and all others in the group have some lesser value down to \( \frac{1}{N_o} \) for the omega individual regardless of group size.

As I have said above, study of larger than optimal sized groups permits determination of what the optimal sized group really is. Below are the steps for such a determination:

Let

\[ v_{\alpha}^{(r)} \]  \text{at } N

represent the velocity of the alpha 1st ranked individual at the N studied with reference to the
value of 1.0 characteristic of alpha at \( N_o \);

\[
\hat{v}_\alpha \text{ at } N_o = \hat{v}_\Omega \text{ at } N \times \frac{N_o}{\Omega}
\]

represent the velocity of the alpha individual in an \( N_o \) group with reference to the observed velocity, \( \hat{v}_\Omega \), of the lowest ranked individual in the larger than optimum group of size \( N \) studied.

It can be shown that:

\[
\hat{v}_\alpha \text{ at } N_o = \hat{v}_\alpha \text{ at } N \times \frac{N_o}{\Omega}
\]  

(5)

and

\[
v(r) \text{ at } N = 1 - \left[ \frac{N-N_o}{N} \left( \frac{N_o-1}{N_o} \right) \right]
\]  

(6)

Therefore:

\[
v(r) \text{ at } N \times \hat{v}_\alpha \text{ at } N_o = \hat{v}_\alpha \text{ at } N
\]  

(7)

Successive values of \( N_o \) are inserted in Equations (5) and (6), and the obtained values used to solve Equation (7). When that value of \( N_o \) is found where Equation (7) produces a \( \hat{v}_\alpha \) at \( N \) identical to that actually observed, then this \( N_o \) represents the optimal group size.

It should have become apparent what I mean by an optimal group size. It is that group size at which there is no inhibition of the velocity of the alpha individual.

Perhaps it will be best to give an actual example of determination of \( N_o \). For a general account of the environment, see my review, "Population Density and Social Pathology," in the Feb. 1962
issue of Scientific American. The particular case selected here is of a group of Osborne-Mendel strain albino rats living in room 1A of the second series of studies and provided with a diet containing a normal level of Vitamin A, 3IU/g. diet.

\[ N = 32 \text{ adult males} \]

\[ \hat{\omega} \text{ at } N = 38 \]

\[ \hat{\Omega} \text{ at } N = 12 \]

Some remarks on the scoring are pertinent. Due to the complex environment studied there were 8 places where social interactions might occur. Thus for the 16 half-hours of observing on a given day the maximum velocity score possible was 128. Two observers made such scores within three days of each other. This gave a maximum score of 256 for each period of observation. The final score for each animal was taken as the means of the three periods of observation, each 4 to 6 weeks from the prior one. Although the maximum mean velocity score was 256 the observed velocity scores for all animals were much less than this, both due to social inhibition of velocities and the fact that all rats slept part of the time as well as generally confining their activities to only a portion of the total field. With this comment let us proceed with determination of \( N_0 \).

Several \( N_0 \) were tried. \( N_0 = 9 \), as a round number gave the best approximation. Inserting \( N_0 = 9 \) in Equation (6):

\[
v^{(r)}(r)_{\alpha \text{ at } N} = 1 - \left[ \left( \frac{32 - 9}{32} \right) \left( \frac{9 - 1}{9} \right) \right]
\]
Inserting \( N_o = 9 \) in Equation (5):

\[
\hat{v} \quad \text{at } N_o = 12 \times 9 = 108
\]

Then employing these calculated values, 0.36 and 108, in Equation (7):

\[
0.36 \times 108 = 38.88
\]

Since this value of 38.88 is very close to the 38.0 observed velocity for the alpha individual at an \( N \) of 32 we may conclude that \( N_o \) closely approximates 9.0. Further approximations show that \( N_o = 8.85 \) gives an exact fit.

Equation (6) so solved = .3583

Equation (5) so solved = 106.20

And inserting these values into Equation (7):

\[
.3583 \times 106.2 = 38.05
\]
5. Calculation of relative velocities

Once $N_0$ has been determined by this process of successive approximations, it is then possible to calculate the expected velocities for all ranked individuals in the group of $N$ studied.

Let

$v_R^{(r)}$ be the relative velocity of any $R$th ranked individual.

Then it can be shown that:

$$v_R^{(r)} = R - N \left[ \frac{1}{N_0} - \frac{1}{N} \left( \frac{N-N_0}{N} \left( \frac{N_0-1}{N_0} \right) \right) \right] + \frac{1}{N_0}$$  \hspace{1cm} (8a)

$$= R - N - \frac{N_0-1}{N} \frac{1}{N-1} + \frac{1}{N_0}$$  \hspace{1cm} (8b)

$$= \frac{(N-R) (N_0-1)}{N(N-1)} + \frac{1}{N_0}$$  \hspace{1cm} (8c)

And for the special case where $N_0 = N$:

$$v_R^{(r)} = R - N \left( - \frac{1}{N_0} \right) + \frac{1}{N_0}$$  \hspace{1cm} (8d)

Then, where

$V_\alpha$ at $N$ is the observed velocity of the alpha ranked individual in the group of $N$ individuals studied

And

$v_R$ is the expected velocity of any $R$th ranked individual.
\[
\nu_R = \frac{\nu^{(r)}}{\hat{\nu}_R} \times \hat{\nu}_\chi \text{ at } N
\]  

(9)

Where \( \hat{\nu}_R \) represents the observed velocity at the \( N \) studied, chi squares may be calculated by Equation (2).
6. Optimal and actual group sizes

I will make these remarks as relevant as possible to the "Condensed Velocity Pen For Mice" described later on in Section 13. Thirty-six males of most strains is likely to represent an N larger than optimal. Suppose that we have selected a number of strains to study comparatively. We do not know how artificial selection has altered the optimal group size with reference to this particular environment. For illustrative purposes consider that there are eight strains whose optimal group sizes, \( N_0 \), are respectively 2, 4, 6, 12, 18, 24, 30 and 36.

We then establish groups of 36 males of each of these strains and make observed estimates of velocity. Because of genetic changes the velocities of the omega animals will likely be observed to be different. Regardless of this variability we may from Equation (6) calculate how much the velocity of the alpha individual is suppressed as a result of membership in a group of 36 individuals. Table III gives the degree of suppression of the alpha individual's velocity relative to that at \( N_0 \). These \( v(\tau) \) values give a somewhat erroneous impression of the impact of increases in group size above \( N_0 \) upon velocity. Considering velocity relative to \( v(\tau) = 1.0 \) at \( N_0 \), it looks as though as \( N_0 \) increases there is more inhibition of velocity at a given excessive N, and then as \( N_0 \) increases further there is less and less inhibition of velocity.

The reason for this apparent contradiction stems from the fact that any inhibition of velocity must be measured against the amount of inhibition possible with reference to a given \( N_0 \).
7. "Social temperature"

Recall that \( v^{(r)} = \frac{1}{N_0} \) represents the maximum inhibition of velocity
in any \( N_0 \). This \( v^{(r)} \) represents the limits of toleration with respect
to the genetic constitution of the species. It represents what I shall
here term the "Social Freezing Point". Any reduction in velocity
below \( v^{(r)} \) exposes the individual to strains upon its physiology and
behavioral stability which it can not long sustain without running
the risk of physical death or behavioral disorganization so extensive
as to preclude any normal participation in the social affairs of the
group. Where sustained maintenance of velocity persists without
physical death. I suspect that the ensuing behavioral disorganization
will prove to be what, on the human level, we call "psychotic disorders".\(^1\)

In evolution as \( N_0 \) increased, genetic alterations must have
arisen permitting life to continue at a reduced \( \frac{v^{(r)}}{\Omega} \). How close a
given relative velocity approaches the social freezing point, \( \frac{v^{(r)}}{\Omega} \), I
shall here call the "Social Temperature", \( v^{(t)} \). Then:

\[
v^{(t)} = \frac{v^{(r)}}{R} \left[ 1.0 - \frac{v^{(r)}}{\Omega} \right] \quad (10a)
\]

\[
= \frac{(N-R) (N_0 - 1)}{N(N-1) \left( \frac{v^{(r)}}{\Omega} - \frac{v^{(r)}}{\Omega} \right)} \quad (10b)
\]

\(^1\) Under the classification of the American Psychiatric Association
"psychotic disorders" includes: schizophrenia, manic depressive
psychoses, involutional psychoses, and paranoia.
Both social velocity, \( v(r) \), and social temperature, \( v(t) \), decrease as velocity rank \( R \) increases (Table I for \( N_0 = 12 \)).

Furthermore, for any \( N_0 \) the social temperature of every ranked individual decreases as \( N \) increases. Consider the cases of \( R = 1 \) (i.e., the alpha individual) and the mean ranked individual, \( \bar{R} \) at \( N \), for \( N_0 = 12 \). Particular emphasis is placed on \( N_0 = 12 \), since there is reason to suspect that this is the most characteristic optimum group size developed among mammals. For both velocity ranks, social temperature decreases as expected (Table II). At each \( N \) the \( v(t) \) for \( \bar{R} \) is exactly half that of \( R = 1 \).
8. The "Social Frost Zone" and psychotic-like disorders

It can be shown that at an infinite $N$ all individuals have been forced to a minimum velocity and thus all are at the social freezing point. At this point social life is patently impossible. The real question is: "Is there some smaller density greater than $N_o$ where for all practical purposes social life can no longer continue?"

Decision on this point again requires consideration of the omega ranked individual in an $N_o$ group. Any social group is not a "sure" or "static" one but is subject to stochastic processes. This means that during some period of time the omega individual will receive less restraints from his associates than would be anticipated from the actual group size. During these times its velocity and social temperature would increase. At other times its velocity will be reduced in relative terms below the tolerable, $1/N_o$, limit, and its social temperature would drop below the social freezing point. Every omega individual in an optimum sized group will, for these reasons, fall below the social freezing point for considerable periods of time. Each of these times will force the passage of the individual into a state, which I believe is truly homologous to psychotic states in humans. I will from now on use the term psychotic to denote states of existence when the social temperature, as here defined, falls below the social freezing point. This means that the incidence of psychoses, with reference to average life span, must be at least 0.083 (i.e., $\frac{1}{N_o} \leq \frac{1}{12} = 0.083$). Whether it will rise higher depends upon whether the increase in group size is sufficient to reduce the social temperature of other individuals ranked above the omega one down toward the level of the omega.
In an $N_o = 12$ the 11th ranked individual, the one just higher ranked than the omega, has at $N_o$ a social temperature of 0.0909 (see Table I). Chance factors will at time force its social temperature down toward the social freezing point. However, I can only suspect that processes of evolution will have been such as to expose only the omega individual to the liability of becoming psychotic. I have therefore taken $0.5 \rho_{R=N-1}$ as a most likely social temperature, which if maintained on the average for any appreciable time will certainly expose such an individual to periodic reductions of $v(t)$ below the social freezing point. This assumed critical $v(t)$ cannot be rigorously defended, but it is obvious that this value cannot be far wrong or groups would contain so many aberrant members as to be non-functional as a group.

By this assumption the critical social temperature in an $N_o = 12$ becomes $0.5 \times 0.0909 = 0.04545$. For $N_o = 12$, $v(t)$ of this value will be called the "Social Frost Temperature" and the range of $v(t)$ below 0.04545 will be called the "Social Frost Zone". Any individual whose $v(t)$ is forced into the Social Frost Zone for any appreciable span of time becomes liable to psychotic episodes.

Frost $v(t)$ can be calculated for any sized $N_o$. See Table III. Here I have considered $N_o$ to vary from 2 to 36. Each of these $N_o$ would represent a particular genetic strain or species. Then the question was asked "Suppose circumstances forced each $N_o$ to live at an $N$ of 36. How would this larger $N$ affect the social temperature of the 1st ranked alpha individual; and what proportion of the members of the group would have their social temperatures forced into the Social Frost Zone?"
For both $N_o = 2$ and $N_o = 4$, the necessity of living in an $N$ of 36 forces the social temperature of even the alpha individual below the Frost $\nu(t)$. Since the alpha individual has the highest social temperature, all its associates will be in an even worse situation. No social group life could long persist under such a relatively great increase from the optimal size.

Similar data for the other $N_o$ are given in Table III. As $N_o$ approaches $N$ a decreasingly smaller proportion of the members of $N$ have their $\nu(t)$ fall within the Social Frost Zone. These data are graphically shown in Figure 1.

When we say that $N$ is larger than $N_o$ it means that for every velocity ranked individual in $N_o$ there are one or more such ranked individuals in $N$. Consider $N_o = 12$ and $N = 48$. $R = 1$ in $N_o = 12$ will in $N = 48$ be represented by $R = 1-4$; $R = 2$ in $N_o = 12$ will in $N = 48$ be represented by $R = 5-8$, etc. In other words at $N$ there will be $N_o$ cohorts each containing $\frac{N}{N_o}$ individuals. These cohorts include the several relative ranks corresponding to the rank at $N_o$. These ranks at $N$ for a particular cohort are defined by:

$$\left[ \frac{R}{N_o} \right] \left[ \frac{N}{N_o} - 1 \right]$$

Cohorts of ranks so calculated are given in Table IV.

Considering $N_o = 12$ to represent an important optimum group size, I further explored the effects produced by increasing $N$ (see Table IV). It was found that, at the incremental increases shown in Table IV, some member of each cohort of ranks, corresponding to a particular rank at $N_o$,
felled within the Social Frost Zone. These data are shown in Figure 2. The social temperatures for each of the twelve ranked individuals at \( N_0 \), as given in Table I, are plotted. Each such point is connected in Figure 2A with the extremes of the social temperatures of the members of the corresponding cohort of ranks at \( N \).

By successive calculations for each \( N \), that rank was determined for which its social-temperature fell nearest the Social Frost Temperature of 0.04545. Such ranks are given in the next to last column in Table IV. This rank divided by \( N \) gives the proportion of \( N \) whose \( v(t) \) fall within the Social Frost Zone. As \( N \) increases a larger proportion of its members become liable to developing psychotic states. These data are graphed in Figure 2B.

By the time \( N = 264 \) all members are exposed to becoming psychotic. It is difficult to conceive of a group maintaining any semblance of cohesion with all its members in such a state or even marginal to it. When \( N = N_0(N_0 - 1) \), half of the members are exposed to developing such states. The essential question becomes: "What is the maximum \( N \), where \( N \) is greater than \( N_0 \), at which the group can still persist in maintaining sufficient social organization to preserve cohesion into a group?"

On other theoretical and empirical grounds I (in "The Social Use of Space") arrived at the conclusion that when \( N \) becomes 7 to 11 times \( N_0 \), the group will either dissolve or make genetic or cultural changes enabling persistence at this greater \( N \). I can only suspect at present that a group cannot persist when more than one-third of its members have their social temperatures within the Social Frost Zone.
9. Smaller than optimal sized groups

So far I have treated only conditions where $N$ exceeds $N_o$. However, with every species living under natural conditions groups do become reduced below optimum levels. I have no empirical data indicating whether actual consequences of living in a lower than optimum group size would in fact lead to the predictions of social velocity and social temperature given by Eqs. (8c) and (10a). Table V provides the theoretical figures for $N=6$, $N_o=12$. Half the members in such a smaller than optimum group size have social velocities and temperature exceeding the maximum of that attained within an optimum group size. On the average velocity doubles with halving of the group from its optimum size. In my paper on "The Social Use of Space" I showed that such a change in velocity will permit reattainment of optimum amounts of satisfaction and frustration from social intercourse. However, in a smaller than optimum group some individuals are characterized by a social hyper-velocity. These hyper-velocity states should be stressful on the individual and when they become fixed life-styles they should be particularly mal-adaptive once the group has increased to optimal size or greater.
10. Relevance to phenomena on the human level

Before terminating these comments about reduction in social tempera-
ture and the consequences of these reductions it may be well to make a
few remarks, which will enable the psychoanalytically oriented reader to
appreciate the relevance of these formulations to the human realm. I
will here refer briefly to some concepts considered in detail in my
paper, "The Social Use of Space":

(1) There is an optimal group size for every species.

(2) There is a basic need felt by each individual for
obtaining a specific amount of satisfaction from
interacting with its associates.

(3) This desired amount of satisfaction may most readily be attained
in an optimal sized group.

(4) Attainment of the desired amount of satisfaction from social
interaction depends upon experiencing a given number of
contacts with associates per unit of time.

(5) This rate of contact producing the desired amount of satis-
faction from social interaction is attained at the optimal
group size.

(6) At this optimal group size half the interactions are satisfying
and half frustrating. This balance is the ideal state.

(7) As the group size increases above the optimum, the number of
interactions having satisfying consequences decreases (even
though contacts actually increase) and the number of inter-
actions of a frustrating nature markedly increases.
(8) Frustration is here used in the sense of an animal, in need of satisfactory interactions with associates, not being responded to in a fashion appropriate to produce such satisfaction. Frustration in this sense becomes equivalent to a restraint or negative sanction imposed by an associate, which has the consequence of reducing the velocity of the frustrated individual.

The logical basis and mathematical derivation of concepts (1) to (8) are given in my paper, "The Social Use of Space". These consequences of increases above optimal group size follow even when all members of the group have identical characteristics. Internal differentiation and stratification among members of the group, as here discussed, represents a second force producing decrements in velocity.

Both sources of restraints (frustrations) increase the absolute amount of frustration and decrease the amount of satisfaction derived from social interaction. Although I have considered alterations in group size as the primary independent variable, because of its ease of manipulation in experimental studies with infra-human animals, the essence of the independent variable is actually the increase in frequency of frustrating experiences. However, the members of a group may develop biases of action toward a particular individual in the direction of primarily responding to it in a manner inappropriate to contributing to the satisfaction of that individual. When that
happens the individual will experience a degree of frustration out of proportion to the actual size of the group. As a consequence of this heightened level of frustration the individual will withdraw socially, reduce its velocity, and attain a reduction of social temperature comparable to membership in a much larger group. Such aberrations in social relationships probably lie at the root of psychoses in human groups.

A word is here in order as to how we may place human social interactions in perspective with closed social groups. The present theoretical formulations, and those in my paper, "The Social Use of Space", has considered all social relations as transpiring within the framework of a closed social group. Membership in such groups provides the opportunity for a certain number of contacts, and thus social interactions, per unit of time. During evolution the physiology and behavior of the species becomes adapted to permit attainment of an optimum amount of satisfaction (along with an equivalent amount of frustration) as a consequence of the existing rate of contact characteristic of the typical group size. The key to the problem lies in the rate of contact.

Evolutionary history modifies physiology to demand a given rate of contact in harmony with having lived in a particular group size. Man is no exception. Through most of his evolution he has lived in relatively closed groups of relatively small size. There are reasons to believe that man lies along an evolutionary path which the optimum group size (of adult members) has a range of 7-19 with a mean of 12.

Obviously, modern man lives in close proximity to many associates. So then what is the group? It can only be conceived from the viewpoint
of a single individual. It becomes that entire assembly of others with which that particular individual can regularly have satisfactory relations half of the time. Yet, though there may be many more than eleven others involved in these relationships, at any moment in time this individual, and therefore all others, must be participating in some structured assembly which on the average involves eleven others. Maintaining an integration in several such partially overlapping groups in time and space places a strain on cultural mechanisms, particularly in a mobile population which periodically forces the new resident to find channels for being accepted into such a system. All such periods of adjustment are initially unsatisfactory and the increased frustrations accompanying acceptance make the individual live through a period when the consequences to him are comparable to having low velocity in a greater than optimal sized closed group.

The final point, whose understanding will facilitate our comparison of the human picture with that of the theoretical considerations of closed social groups, pertains to the incidence of psychotic-like states produced by low social temperatures. For example consider the findings of Clausen and Kohn (J. A. Clausen and M. L. Kohn, Relation of schizophrenia to the social structure of a small city, pp. 69-94 in Epidemiology of mental disorders. Benjamin Pasamanick (Ed.), Pub. No. 60, A.A.A.S. Washington D. C., 1959) for Washington County, Maryland. For all categories of psychotic disorders the annual rate of first admissions to mental hospitals was 34.4 per 100,000 population. Persistence of this rate from 15-65
years of age leads to 0.17 of the population having been admitted to mental hospitals at some time during their life. This probability of developing a psychotic disorder is essentially the same as that which obtains for $N_0=12$ but $N=36$ (Table III). Assuming the theory to be correct we may say that in Washington County, Md., the average individual experiences interactions with associates as if he had been a member of a closed group three times optimal size. Probably the most extreme case of psychopathology for the United States is that cited of Srole et al (Leo Srole, Thomas Langer, and T. A. C. Rennie. Midtown Manhattan: The Mental Health Story, McGraw-Hill, 1960). They found severe psychopathology in 0.37 of the population sampled. Assuming that they in fact were able to recognize all who at sometime in their life would enter into a psychotic state for some extended period of time, we have here a situation comparable to that in which the members lived in a closed social group eight times the optimal size (Table IV). A large society can perhaps tolerate a small segment of it to develop such a degree of psychopathology, but if the larger society were itself forced into such a state, a drastic reorganization of the social structure would be necessary in order to develop a new pattern of social interaction in which the average individual would be as if he were a member of a closed group of eleven others.
11. General remarks concerning the experimental study of velocity

I am here considering the use of small mammals such as rodents and shrews which may be housed in relatively small experimental pens in groups which may exceed by several times the optimal size. My own experience in studying velocity has dealt with laboratory bred strains of mice and rats; from which studies the concept of velocity has been an outgrowth. None of these results are actually in print yet, although the essential details are included in my paper, "The Social Use of Space" submitted for inclusion as a chapter in the book, tentatively called "Physiological Mammalogy" to be published by Academic Press. Much of my studies (see Feb. 1962 issue of Scientific American) have involved groups purposely allowed to reach rapidly a greater than optimal group size. The resultant data, including that on velocity, is now being programmed for machine analysis.

It is likely to be two to three years before all this information is prepared for publication. In the meantime this informal discussion of velocity may be of some use to others, who may wish to explore the concept.

You will note that so far I have not mentioned social hierarchies. In the first place, open conflicts, revealing status relationships, most particularly characterize the initial phases of social organization of individuals brought into association as adults. If animals are permitted to mature together from weaning, marked antagonisms become sublimated by adulthood. Among adults so matured, clear-cut status contentions may only be recognized within the upper half of the velocity ranks. Among
these there is a high positive correlation between velocity and hierarchy rank. For the remaining individuals social withdrawal has been so extreme that as rule they neither attack others or elicit attack upon themselves.

In my studies of adult male Osborne-Mendel strain rats living in closed social groups as velocity decreased:

a. Scar tissue from wounds decreased (i.e., social withdrawal and reduction in velocity tends to take place relatively early in life).

b. Relative amount of fat increases.

c. Adrenal, heart and kidney size decreases.

d. Sexual behavior becomes more aberrant (there is more homosexuality) until at the lowest velocity ranks there is very little participation in sexual activities.

These results only sketchily reflect the profound alterations which accompany reduction in velocity. As velocity decreases there develops a decreased ability to utilize all cues requisite for an appropriate response. This conclusion derives from observations of maternal and sexual behavior. Consider the latter. High velocity males only mount receptive females. Those with slightly lesser velocity also mount females not completely receptive. With further decrements in velocity males mount non-receptive females and other adult males. With still further reduction in velocity juveniles of both sexes are included as objects of sexual approach. And finally with extreme reduction of velocity there develops a complete cessation of sexual behavior. In a perhaps real sense this divergence from appropriate
sexual behavior represents creativity. As velocity decreases the objects approached become less probable until at a very low velocity sex behavior abruptly ceases. In this sense of the degree of unusualness of sexual behavior the most creative rat is one with quite low, but not lowest velocity.

Having made these preliminary remarks we may ask: "What types of further studies of velocity promise to be most fruitful?"

In the first place there needs to be confirmation that the velocities of the several members of a group will differentiate as predicted. This confirmation requires study of groups at an $N$ larger than the suspected optimum. Only by so doing can the optimal group size be determined. Once $N_0$ is known for the species and strain studied then this group size becomes the basis for calculating expected velocities at any $N$ studied.

Initially one may wish to bypass such determinations and arbitrarily select an $N$ for study. Comparisons may be made between $N$ and $3N$ where $N$ is 10 or 12. In this case the hypothesis holds that the velocity of the omega individual will remain unchanged regardless of $N$, whereas for the alpha individual the velocity at $3N$ will be only 0.389 that at $N$. If these two hypotheses prove correct we can be fairly certain of the general formulation.

On the other hand one may be unconcerned with theory, but rather have an interest in using velocity as the independent variable. Here one may utilize a single strain of a given species or compare two strains of the same species. However, in the latter case it is well to keep in mind that each strain may have its own $N_0$. Relative magnitude
of $N_0$ for the two strains compared may be judged by the fact that the larger $v/v_\alpha \Omega$, the larger is $N_0$. 
12. The rationale for construction of an experimental enclosure

Velocity reflects the degree of social withdrawal. For this reason any enclosure or pen designed to house a closed social group should provide sub-regions within it where any individual may retreat and thus avoid social interaction. All such places of retreat should have equal access to the remaining portion of the field where social interactions among adults are accentuated. This demands that ideally the field be circular with places of retreat lying peripheral to a central area where the presence of such resources as food, water and nesting material increase the probability of contact among active animals.

Another criterion of the field is that the mean free path should be large with reference to the likelihood of one animal contacting another when the space is inhabited by an optimal sized group. I have considered in detail the underlying logic of this criterion in my paper, "The Social Use of Space". It is based upon the premise that animals can gain satisfaction from social interaction. When two individuals have each not met another for a considerable time, but then meet each other, each at the time of meeting will be in a need state for social interaction. They will therefore behave appropriately toward each other, such that each individual's need is satisfied. Following such an interaction each goes into a refractory period of temporary satiation of the need for social interaction. If either is, during such a refractory period, contacted by some third individual who is in the social need state,
the contacted individual will not respond appropriately to the approaching individual. This latter will, because of this inappropriate response, be thrown into a false or "frustrating" refractory period during which if he is contacted by a fourth individual in the social need state, he will also respond inappropriately and this fourth individual will also be thrown into a frustrating refractory period. The smaller the field, the smaller the mean free path, and thus the greater the probability of contacts resulting in frustration. Similarly, with a given field an increase in group size also decreases mean free path. Where the size and structure of the field is in harmony with the genetic constitution of the contained species, the contained group is an \( N_o \) one. Under such ideal circumstances half the contacts will be satisfying and half frustrating.

Any one familiar with home ranges of animals in their natural habitat realizes that the area inhabited by a group is large with reference to any artificial habitat feasible for construction for experimental purposes. This means that the physical structure of an experimental enclosure must provide impediments to movement which will in effect increase the mean free path with regard to the interval between contacts. The pen described in Section 12 of this account utilizes vertical structuring and isolation of peripheral place of retreat as means for increasing the mean free path.

The \( N_o \) determined experimentally for each strain of each species in such a habitat has meaning only with reference to this particular habitat. \( N_o \) will increase or decrease as the mean free path is increased or decreased by the physical structure of the environment.
A CONDENSED VELOCITY PEN FOR MICE

Figures 3 and 4 present the essential details of the design. This design has as its basis construction of a field where (a) the mean free path is large, (b) the portion of the field where social interactions occur is easily observable and physically distinct from that portion where it is possible for the mice to withdraw from social interaction. The plan's intent is to state specifications for a container, which will serve as culture medium for animals such as the house mouse. (Increasing all measurements, except for height, by a factor of two will make the field suitable for the study of velocity utilizing rats.)

Comments Concerning Construction

1. Panel C should be removable so as to permit cleaning of the shelves and floor of the eight retreat pens. Care should be exercised in providing for the placement of this panel such that the surface facing the center of the field presents no opportunity for the mice to climb up the outer surface and out of the enclosure. The lower and upper window screen (or 1/4" hardware cloth) portions of Panel C may be fixed and only the central solid galvanized metal portion left removable.

2. Panels A and B and the roof of the retreat pens should be of a solid material of sufficiently rigid construction to make the assembled structure quite stable.

3. The doors from the retreat pens should be two inches wide and four high. This height is to permit passage over a two-inch layer of sawdust maintained on the floor to absorb urine and moisture from feces.

4. The six-by-six inch baffles in front of the doors from the
retreat pens facilitate escape of subordinate animals and permit making a definition of when an animal is out in the central velocity observation field. An animal is to be given a velocity score only if it has emerged out into the field from behind one of these baffles.

5. The one-quart chicken water dispenser is to be placed on the solid top of the food hopper. This conserves space and insures symmetry of the field with reference to access to primary response situations. Eight one and one-half inch wide ramps covered with window screen provide access from the floor to the top of the food hopper. Bases of these ramps are to be placed as shown in Figure 3.

6. Nest boxes: All nest boxes (Fig. 5) are removable from the outside through Panel B. This means that square openings must be prepared through Panel B just slightly greater than six-by-six inches so that the boxes may be slid through and onto the appropriate shelves. The back side of the nest box being larger prevents the nest box from sliding too far on the shelf. Sliding metal doors make possible the capture of animals in the boxes. It is suggested that on surveys of boxes used by the subjects, all doors be closed as rapidly and quietly as possible. Such surveys should occur during times of minimum activity, 0700 to 0800, when lights change from bright to dim at 1000. The air vent of bent copper tubing prevents suffocation of animals during surveys. All boxes are to be cleaned periodically, most old nesting material removed, and a one-inch layer of sawdust placed over the floor.

7. Ramps to nesting box shelves (Figure 6): These ramps are to be of three-quarter inch Boards, one and one-half inches in diameter,
and of the lengths given in Figure 6. The surface of the ramps is to be covered with window screen to enable greater ease of climbing. Attach ramps to shelves and floor with plate C fitting against the ramps.

8. Lights: Directly above the center of the field suspend a reflector containing a 7 1/2-watt and a 100-watt lamp. The lower outer edge of the reflector is to be six inches below the top of the pen. Except when animals are removed from the boxes, the field cleaned, or food and water added, these lamps will be the only source of light in the room containing the velocity pens. The 7 1/2-watt lamp remains on all the time. The 100-watt lamp is to be turned on at 2200 by an automatic clock switching device and turned off at 1000. This cycle will establish a 24-hour rhythm of activity with the period of increased activity falling between 1000 and 2200. Means should be provided for moving the reflector and lamps to one side when it is necessary to climb over into the field. Climbing over can be accomplished with two step ladders, one on the outside of the pen and one on the inside.

9. Nesting material: Prepare strips of paper toweling, one-half inch by six inches. These are to be scattered as loose packs between the food hopper and the bases of the ramps to the water source. Provision of nesting material in this central location further enhances it as the place of primary response situations and thus increases the probability of the field outside the retreat pens actually becoming the general location where most social interaction occurs. Maintain a record of the amount of nesting material deposited in each box. There
should develop a significant correlation between amount of nesting material in boxes, and the velocity of mice inhabiting the boxes. Low velocity males should transport less nesting material, although if velocity rank is actually established very early in life the opposite correlation may develop.

10. Observation platform: Construct an observation platform upon which the observer can sit and with equal ease look over into either of two adjoining pens.
14. Initiation of a study of velocity

Initial studies are likely to prove most profitable if the study of velocity is confined to males in either all male groups or in groups in which males outnumber females. In the latter case fix the ratio of males to females at 2:1. Here females will merely serve as background stimuli for eliciting more social interactions among males. Start with several pregnant females whose due dates are approximately the same. Confine each female to one of the eight peripheral retreat pens by sealing the door providing access to the central area. Place an auxiliary nest box on the floor along with a supply of food and water. When the pups are 10-12 days of age cross foster so that each female for the latter portion of lactation rears as near as possible an equal number of her own progeny and that of other females and so that each new litter is of the same size. I would recommend that all females used should have reared at least one other litter and that the litter size be fixed at six: 4 males and 2 females or six males. It will be advisable to have some auxiliary females with litters of the same age so that the litter of females confined in the retreat pens may be supplemented provided they fail to contain enough males.

At 30 days of age remove the mothers, and open the door providing access to the central area. Lay a trail of food from the door to the central food hopper. At the end of 5 days remove the food and water and the auxiliary nest boxes from the retreat pens. By this time the young mice (or rats) should be fairly well accommodated to the use of the central pen at least. In time exploration will extend to the entire enclosure.
At 10-12 days of age mark each mouse by clipping one or two toes according to a code system preferred by the experimenter. Fingerling fish tags may be used instead, but tow-clipping is quite satisfactory.

For mice the first assessment of velocity should not begin until they are four months of age. With rats such measurements of velocity should begin at nine months of age. According to my experience these are ages at which velocity in these species has become fairly well fixed. Three to six sets of velocity measurements should be taken during the next three months.
15. Marking for visual identification at a distance

Some method of marking the pelage so as to permit identification of each individual by the viewer who is outside the enclosure is necessary. I have utilized a simple code which permits marking many individuals. This requires marking certain regions on the animal with spots of dye or removal of the pelage at these locations. See Table VI.

<table>
<thead>
<tr>
<th>Spot Number</th>
<th>Region of body</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shoulder</td>
</tr>
<tr>
<td>2</td>
<td>Mid back</td>
</tr>
<tr>
<td>3</td>
<td>Rump</td>
</tr>
<tr>
<td>4</td>
<td>Rt. fore limb</td>
</tr>
<tr>
<td>5</td>
<td>Rt. mid side</td>
</tr>
<tr>
<td>6</td>
<td>Rt. hind limb</td>
</tr>
<tr>
<td>7</td>
<td>Lft. fore limb</td>
</tr>
<tr>
<td>8</td>
<td>Lft. mid side</td>
</tr>
<tr>
<td>9</td>
<td>Lft. hind limb</td>
</tr>
</tbody>
</table>

Always mark two and only two of these locations. Thus there never remains any doubt as to how many spots one should look for on an animal. This coding permits marking 36 individuals. A mark on the head can be used to indicate a 100 series. This increases to 72 the number of individuals which can be marked with either a single color dye or a depilatory. Each additional dye increases by 72 the number of individuals which can be marked. I have used black hair dye and red stamp-pad ink for marking albino animals, and depilatory for removing spots of hair on black and dark pigmented animals. The above two dyes enable identification for three months following marking. Hydrogen peroxide should prove satisfactory for bleaching spots on animals with pigmented fur, but I have never used this procedure.
16. Vitamin A and tranquilizers

In my studies of velocity is included a comparison of two groups of Osborne-Mendel rats where N=32 and the estimated N₀=9. Their histories with regard to variables possibly affecting them were identical with the exception that one received a diet containing 3 International Units (I.U.) of Vitamin A per gram of diet, while the other received 12 IU/g. diet. The 3IU diet represents a high normal level of Vitamin A. The intensity of fighting was much reduced among the 12IU groups. Other lines of evidence suggested that rats of the 12IU groups developed a reduced capacity to discriminate among available stimuli. As a consequence those stimuli of associates, which otherwise would have elicited aggression, failed to do so. There resulted a much reduced inhibition of velocity at the much greater than optimum group size in which they were forced to live, than was true for the 3IU group (see Fig. 7). These velocity-velocity rank curves in the figure represent regression lines fitted through the observed points by eye. From it for the 3IU group \( \hat{v}_\alpha =38 \) and \( \hat{v}_\Omega =12 \). From it for the 12IU group \( \hat{v}_\alpha =58 \) and \( \hat{v}_\Omega =12 \). Based on the 3IU as the normal diet group,\( N_0=9 \), (see calculation in Section 4 of this paper).

The conclusion from these observations is that an increase in Vitamin A above normal levels acts like a tranquilizer. How this happens is not known. The suspicion is that in some way an increase in Vitamin A reduces the amount of tryptophan which becomes transformed into serotonin. Irrespective of the uncertainties with regard to how Vitamin A leads to an increase in velocity among all members ranked
above the omega, lowest ranking one, these observations suggest an
hypothesis suitable for empirical investigation. Consider the following:
\[ N_0 = 10, N = 30, v_r^{(r)} = 0.1 \]

Let
\[ Z = \text{One unit of tranquilizer}. \]

At \( N = 30 \) and no tranquilizers, \( v_r^{(r)} = 0.4 \). Judging from current results
an increase in Vitamin A in the diet from 3IU to 19IU would increase \( v_\alpha \)
from 0.4 to 0.7. Thus \( Z = 19 - 3 = 16 \) IU of Vitamin A above the prior level.

<table>
<thead>
<tr>
<th>Normal Diet</th>
<th>Total Vitamin A</th>
</tr>
</thead>
<tbody>
<tr>
<td>(3IU Vit A/g. diet)</td>
<td>in IU/g. diet</td>
</tr>
<tr>
<td>Plus 1Z</td>
<td>19</td>
</tr>
<tr>
<td>Plus 2A</td>
<td>35</td>
</tr>
<tr>
<td>Plus 3Z</td>
<td>51</td>
</tr>
<tr>
<td>Plus 4Z</td>
<td>67</td>
</tr>
<tr>
<td>Plus 5Z</td>
<td>83</td>
</tr>
</tbody>
</table>

Now suppose we had six experimental groups, a normal and one on each
of the higher Vitamin A diets. What might be the anticipated results?

These should approximate those of the six curves, A to F, in
Figure 8. Curve A represents the depression of velocity by a threefold
increase of \( N \) above \( N_0 \). Curve B represents the elevation anticipated by
the addition of one unit of \( Z \) (16IU Vit. A/g. diet). Curves A and B are
essentially that found in my studies. The further increase of \( Z \) to the
\( 2Z + \) normal level should elevate velocity to the point that the velocity
of the alpha individual is up to the normal level anticipated on a normal
diet where \( N = N_0 \).
What happens with further increases in Z remains quite conjectural. I suspect that the velocity of the alpha individual at \( N_0 \) represents a maximal velocity. Further increases in Z should so reduce discrimination, that each member becomes so unaware of his associates, that situation becomes as if the actual \( N \) were less than the true \( N_0 \) and, furthermore, as if \( N_0 \) were less than 10. If this deduction proves true, it will mean that with 3Z added to the normal diet, \( v^{(r)} \) remains at 1.0 but that the velocity of all lower ranked individuals increases, with \( v^{(r)} \) increasing to 0.4. Since \( v^{(r)} = \frac{1}{\Omega} \), the apparent \( N_0 \) following a 3Z addition to the diet will be 2.5. As further increments of Z are added to the diet, discrimination decreases and velocity increases. At 4Z the apparent \( N_0 \) is 1.67, and at 5Z \( N_0 = 1.0 \).

When \( N_0 = 1.0 \), it means that every individual is suffering from such impairment of discrimination that it can no longer detect any other individual as being any different from itself. There will be no restraints or negative sanctions imposed by any individual on any other, and therefore every individual will exhibit maximum velocity. This represents an end state as destructive as that produced by a very large \( N \). At 5Z (so defined) no individual perceives any other as differing from himself. This condition precludes role formation and thus no structured social organization is possible. At a very large \( N \), theoretically at an infinite \( N \), but for all practical purposes at 20N, every individual is reduced to the minimum velocity at which it becomes perceptually blind to all other associates. With no individual aware of any associate, no social organization is possible. These conclusions represent the theoretical reasons why study of velocity is
important.

To return to tranquilizers: Vitamin A has the peculiar property of being stored in the liver. Based on the levels of Vitamin A I used in my diets the levels anticipated at 1 to 5Z supplements eaten to 12 months of age by rats should roughly be as shown in Table VII.

The synthetic diets used by me were prepared for me by Nutritional Biochemical Corporation (21010 Miles Avenue, Cleveland 28, Ohio) to my specifications. Cost per pound was slightly in excess of one dollar. Diets, Calhoun, Nos. 11, 12 and 13 are identical except that they contain respectively 3, 6 and 12 IU Vit A/g. diet. Nutritional Biochemical Company could fabricate diets with higher Vitamin A contents to conform to the Z levels herein listed. It will be at least sometime during the year 1964-65 before I return to studies of Vitamin A revelocity. Should anyone else initiate such studies before that time and procure diet from Nutritional Biochemical (or from some other source based on the formula I can supply) I suggest that they be designated as follows:

<table>
<thead>
<tr>
<th>Diet</th>
<th>IU Vit A/g. Diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calhoun No. 14</td>
<td>19</td>
</tr>
<tr>
<td>&quot;</td>
<td>15</td>
</tr>
<tr>
<td>&quot;</td>
<td>16</td>
</tr>
<tr>
<td>&quot;</td>
<td>17</td>
</tr>
<tr>
<td>&quot;</td>
<td>18</td>
</tr>
</tbody>
</table>

Much more is known about other pharmacological agents with tranquilizing effects. Where it is possible to provide such an agent in the drinking water or in the food, studies could be made of their effect on
velocity. The minimum effort required to gain insight into the effect of such an agent is to study three groups, each of 30 individuals. No agent given to one group. Select a dosage of the agent suspected to have an effect. Give this dosage to another group and twice the amount to the third group. Extrapolation from these effects on velocity should lead to delineation of a 1:2 to 5:2 series of dosages, the upper range of which should increase all individuals to the maximum velocity level. Tranquilizers directly affecting intensity of activity should be avoided. Only those tranquilizers should be employed which reduce capacity to discriminate or which reduce intensity of response to stimuli.


## Appendix

### Calhoun - Behavior Diets

#### Vitamins (except A)

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>gms./100 kilo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod liver oil U.S.P.*</td>
<td>500.00</td>
</tr>
<tr>
<td>K(menadione sodium bisulfite)*</td>
<td>100.00</td>
</tr>
<tr>
<td>E (DL alpha tocopherol N.F.)*</td>
<td>25.00</td>
</tr>
<tr>
<td>E (DL alpha tocopherol acetate N.F.)*</td>
<td>25.00</td>
</tr>
<tr>
<td>B (nicotinic acid)*</td>
<td>7.50</td>
</tr>
<tr>
<td>D concentrate</td>
<td>2.75</td>
</tr>
<tr>
<td>thiamine hydrochloride</td>
<td>0.50</td>
</tr>
<tr>
<td>riboflavin</td>
<td>0.75</td>
</tr>
<tr>
<td>pyridoxine hydrochloride</td>
<td>0.63</td>
</tr>
<tr>
<td>calcium pantothenate</td>
<td>5.00</td>
</tr>
<tr>
<td>choline hydrochloride</td>
<td>250.00</td>
</tr>
<tr>
<td>p-amino benzoic acid</td>
<td>6.00</td>
</tr>
<tr>
<td>biotin</td>
<td>0.03</td>
</tr>
<tr>
<td>folic acid</td>
<td>0.05</td>
</tr>
<tr>
<td>niacinamide HCl</td>
<td>3.75</td>
</tr>
<tr>
<td>B&lt;sub&gt;12&lt;/sub&gt;</td>
<td>0.01</td>
</tr>
<tr>
<td>ascorbic acid</td>
<td>50.00</td>
</tr>
<tr>
<td>inositol</td>
<td>25.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1001.97</strong></td>
</tr>
</tbody>
</table>

1/ All weights except those followed by an asterisk based on Table I, p. 403 of Greenstein, Jesse P., Sanford M. Birnbaum, Milton Winitz, and M. Clyde Otey. Quantitative nutritional studies with water-soluble, chemically defined diets. I. Growth, reproduction and lactation in rats. Archives of Biochemistry and Biophysics, 1957, 72, 396-416.
Calhoun - Behavior Diets

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>% of 99 Kilo Remainder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin free casein</td>
<td>18</td>
</tr>
<tr>
<td>corn starch</td>
<td>30</td>
</tr>
<tr>
<td>sucrose</td>
<td>30</td>
</tr>
<tr>
<td>Crisco (fat component)</td>
<td>10</td>
</tr>
<tr>
<td>alphacel</td>
<td>8</td>
</tr>
<tr>
<td>H. M. W. salt mixture(^1)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

\(^1\) J. Nutr., 1937, 14, 273

Vitamin A Acetate in diet

<table>
<thead>
<tr>
<th>Diet Number</th>
<th>I.U./gm. diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>13</td>
<td>12</td>
</tr>
</tbody>
</table>

Diets fabricated by Nutritional Biochemicals Corp., 21010 Miles Avenue, Cleveland 28, Ohio.

In all situations where this diet was used it was presented in powdered form. At all times every rat had free choice of an ample supply.

John B. Calhoun
Laboratory of Psychology, NIH
Building 10, Room 2N306
National Institutes of Health
Bethesda 14, Maryland
### Table I

\( N_0 = 12, N = 12 \)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Social Velocity ( v(r) )</th>
<th>Social Temperature ( v(t) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2</td>
<td>0.917</td>
<td>0.909</td>
</tr>
<tr>
<td>3</td>
<td>0.833</td>
<td>0.818</td>
</tr>
<tr>
<td>4</td>
<td>0.750</td>
<td>0.727</td>
</tr>
<tr>
<td>5</td>
<td>0.667</td>
<td>0.636</td>
</tr>
<tr>
<td>6</td>
<td>0.583</td>
<td>0.545</td>
</tr>
<tr>
<td>7</td>
<td>0.500</td>
<td>0.455</td>
</tr>
<tr>
<td>8</td>
<td>0.417</td>
<td>0.363</td>
</tr>
<tr>
<td>9</td>
<td>0.333</td>
<td>0.273</td>
</tr>
<tr>
<td>10</td>
<td>0.250</td>
<td>0.182</td>
</tr>
<tr>
<td>11</td>
<td>0.167</td>
<td>0.091</td>
</tr>
<tr>
<td>12</td>
<td>0.083</td>
<td>0.000</td>
</tr>
</tbody>
</table>
Table II

\[ N_0 = 12, \text{ } N \text{ varies, } v^{(r)} \alpha \text{ at } N_0, \quad v^{(r)} \Omega \text{ at } N_0 = 1.0, \quad v^{(r)} \Omega = 0.083 \]

Effect of increasing \( N \) on the social temperatures of the alpha and the mean ranked (\( R \)) individuals.

<table>
<thead>
<tr>
<th>( N )</th>
<th>( v^{(r)} \alpha \text{ at } N )</th>
<th>( v^{(r)} \Omega \text{ at } N )</th>
<th>( v^{(r)} \Omega \text{ at } N )</th>
<th>( v^{(r)} \Omega \text{ at } N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>1.000</td>
<td>0.542</td>
<td>1.000</td>
<td>0.500</td>
</tr>
<tr>
<td>24</td>
<td>0.542</td>
<td>0.313</td>
<td>0.501</td>
<td>0.250</td>
</tr>
<tr>
<td>48</td>
<td>0.314</td>
<td>0.199</td>
<td>0.251</td>
<td>0.126</td>
</tr>
<tr>
<td>72</td>
<td>0.236</td>
<td>0.160</td>
<td>0.167</td>
<td>0.084</td>
</tr>
<tr>
<td>96</td>
<td>0.199</td>
<td>0.141</td>
<td>0.127</td>
<td>0.064</td>
</tr>
<tr>
<td>120</td>
<td>0.176</td>
<td>0.130</td>
<td>0.101</td>
<td>0.056</td>
</tr>
<tr>
<td>144</td>
<td>0.160</td>
<td>0.122</td>
<td>0.084</td>
<td>0.042</td>
</tr>
<tr>
<td>168</td>
<td>0.150</td>
<td>0.117</td>
<td>0.073</td>
<td>0.037</td>
</tr>
<tr>
<td>192</td>
<td>0.140</td>
<td>0.112</td>
<td>0.062</td>
<td>0.031</td>
</tr>
<tr>
<td>216</td>
<td>0.135</td>
<td>0.109</td>
<td>0.057</td>
<td>0.029</td>
</tr>
<tr>
<td>240</td>
<td>0.129</td>
<td>0.107</td>
<td>0.050</td>
<td>0.026</td>
</tr>
<tr>
<td>264</td>
<td>0.125</td>
<td>0.106</td>
<td>0.045</td>
<td>0.025</td>
</tr>
</tbody>
</table>

\(^1\) The log of \( v^{(r)} \) as a function of log \( N \) forms a straight line.
Table III

No varies, N = 36

Their effect on social temperature

<table>
<thead>
<tr>
<th>No</th>
<th>( v(\tau) )</th>
<th>( v(\tau) )</th>
<th>( v(\tau) )</th>
<th>Frost ( v(\tau) )</th>
<th>Proportion of N in Frost Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.500</td>
<td>0.528</td>
<td>0.056</td>
<td>0.2500</td>
<td>1.000</td>
</tr>
<tr>
<td>4</td>
<td>0.250</td>
<td>0.333</td>
<td>0.011</td>
<td>0.1667</td>
<td>1.000</td>
</tr>
<tr>
<td>6</td>
<td>0.167</td>
<td>0.306</td>
<td>0.167</td>
<td>1.000</td>
<td>0.611</td>
</tr>
<tr>
<td>8</td>
<td>0.125</td>
<td>0.319</td>
<td>0.222</td>
<td>0.0714</td>
<td>0.333</td>
</tr>
<tr>
<td>10</td>
<td>0.100</td>
<td>0.350</td>
<td>0.278</td>
<td>0.0555</td>
<td>0.222</td>
</tr>
<tr>
<td>12</td>
<td>0.083</td>
<td>0.389</td>
<td>0.332</td>
<td>0.0455</td>
<td>0.167</td>
</tr>
<tr>
<td>14</td>
<td>0.071</td>
<td>0.432</td>
<td>0.389</td>
<td>0.0384</td>
<td>0.125</td>
</tr>
<tr>
<td>16</td>
<td>0.063</td>
<td>0.480</td>
<td>0.445</td>
<td>0.0334</td>
<td>0.100</td>
</tr>
<tr>
<td>20</td>
<td>0.050</td>
<td>0.578</td>
<td>0.556</td>
<td>0.0263</td>
<td>0.074</td>
</tr>
<tr>
<td>24</td>
<td>0.042</td>
<td>0.681</td>
<td>0.667</td>
<td>0.0218</td>
<td>0.059</td>
</tr>
<tr>
<td>30</td>
<td>0.033</td>
<td>0.859</td>
<td>0.833</td>
<td>0.0172</td>
<td>0.038</td>
</tr>
<tr>
<td>36</td>
<td>0.028</td>
<td>1.000</td>
<td>1.000</td>
<td>0.0143</td>
<td>0.028</td>
</tr>
</tbody>
</table>
Table IV

$N_0=12$, $N$ varies

Effect of $N$ on the number of individuals approaching or entering the Social Frost Zone (See Figure 2)

<table>
<thead>
<tr>
<th>Rank at $N_0$</th>
<th>$N$</th>
<th>Cohort of Ranks at $N$</th>
<th>Range of $v(t)$ from Eq. (10b)</th>
<th>Rank nearest Frost $v(t)$</th>
<th>Proportion of $N$ in Frost Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>264</td>
<td>1 to 22</td>
<td>0.04545 to 0.04182</td>
<td>1</td>
<td>1.000</td>
</tr>
<tr>
<td>2</td>
<td>240</td>
<td>21 to 40</td>
<td>0.04581 to 0.04184</td>
<td>23</td>
<td>0.908</td>
</tr>
<tr>
<td>3</td>
<td>216</td>
<td>37 to 54</td>
<td>0.04625 to 0.04186</td>
<td>40</td>
<td>0.819</td>
</tr>
<tr>
<td>4</td>
<td>192</td>
<td>49 to 64</td>
<td>0.04679 to 0.04188</td>
<td>53</td>
<td>0.729</td>
</tr>
<tr>
<td>5</td>
<td>168</td>
<td>57 to 70</td>
<td>0.04748 to 0.04192</td>
<td>62</td>
<td>0.637</td>
</tr>
<tr>
<td>6</td>
<td>144</td>
<td>61 to 72</td>
<td>0.04837 to 0.04196</td>
<td>66</td>
<td>0.549</td>
</tr>
<tr>
<td>7</td>
<td>120</td>
<td>61 to 70</td>
<td>0.04958 to 0.04202</td>
<td>66</td>
<td>0.458</td>
</tr>
<tr>
<td>8</td>
<td>96</td>
<td>57 to 64</td>
<td>0.05132 to 0.04210</td>
<td>62</td>
<td>0.365</td>
</tr>
<tr>
<td>9</td>
<td>72</td>
<td>49 to 54</td>
<td>0.05399 to 0.04225</td>
<td>53</td>
<td>0.278</td>
</tr>
<tr>
<td>10</td>
<td>48</td>
<td>37 to 40</td>
<td>0.05851 to 0.04255</td>
<td>39-40</td>
<td>0.198</td>
</tr>
<tr>
<td>11</td>
<td>24</td>
<td>21 to 22</td>
<td>0.06522 to 0.04351</td>
<td>22</td>
<td>0.125</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>12 to 12</td>
<td>0.00000 to 0.00000</td>
<td>12</td>
<td>0.083</td>
</tr>
</tbody>
</table>
Table V

\( N = 6, N_o = 12 \)

Effect of sub-optimal group-size on social velocity and social temperature

<table>
<thead>
<tr>
<th>R</th>
<th>( v(r) )</th>
<th>( v(t) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.917</td>
<td>2.0</td>
</tr>
<tr>
<td>2</td>
<td>1.550</td>
<td>1.6</td>
</tr>
<tr>
<td>3</td>
<td>1.183</td>
<td>1.2</td>
</tr>
<tr>
<td>4</td>
<td>.817</td>
<td>.8</td>
</tr>
<tr>
<td>5</td>
<td>.450</td>
<td>.4</td>
</tr>
<tr>
<td>6</td>
<td>.083</td>
<td>.0</td>
</tr>
</tbody>
</table>
Table VI

Thirty-six basic pelage number designations possible from utilizing pelage marking scheme shown in Figure 1.

<table>
<thead>
<tr>
<th>12</th>
<th>13</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>24</td>
<td>34</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>16</td>
<td>26</td>
<td>36</td>
</tr>
<tr>
<td>17</td>
<td>27</td>
<td>37</td>
</tr>
<tr>
<td>18</td>
<td>28</td>
<td>38</td>
</tr>
<tr>
<td>19</td>
<td>29</td>
<td>39</td>
</tr>
</tbody>
</table>

Using a mark on the head as a 100 mark increases to 72 the number of animals which can be marked by this scheme. Each additional color adds another 72 animals.
Table VII

Possible levels of Vitamin A in rats after 12 months on diet

<table>
<thead>
<tr>
<th>Z supplement to normal diet</th>
<th>IU supplement per g. diet</th>
<th>Vitamin A content of whole livers in International Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>None (i.e., 3IU Vit A/g. diet)</td>
<td>3</td>
<td>20,000</td>
</tr>
<tr>
<td>1Z</td>
<td>19</td>
<td>50,000</td>
</tr>
<tr>
<td>2Z</td>
<td>35</td>
<td>80,000</td>
</tr>
<tr>
<td>3Z</td>
<td>51</td>
<td>110,000</td>
</tr>
<tr>
<td>4Z</td>
<td>67</td>
<td>140,000</td>
</tr>
<tr>
<td>5Z</td>
<td>83</td>
<td>170,000</td>
</tr>
</tbody>
</table>
CONDENSED "VELOCITY" PEN FOR MICE

Fig. 3 FLOOR PLAN

John B. Colkova 22 Aug. 62
CONDEMNED VELOCITY PEN FOR MICE

FIG. 6 Ramps

Ramp Lengths

a. Between Bore 1 = 26".
b. Between Bore 1 and Floor = 16".

These lengths produce a lesser slope to the ramps than shown above.

John B. Colahan Re-Aug. 62