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Conceptual structures as damped harmonic oscillators

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Abstract. This paper serves to examine certain hypotheses about the effect of information on cognitive processing generated by the Galileo model. This model proposes that objects of cognition are points within a multidimensional continuum, the definition of any object being its structural relation to all other objects in the continuum, and any change in structure can be modeled by Newtonian mechanics. This paper tests the hypothesis that new information will induce motion described by the equation for a damped harmonic oscillator, and that regions of the continuum where information is not directed will display motion as described by DeBroglie's equation. Results tentatively support the hypotheses, and the relation of this conceptualization with compatible models of physical reality is discussed.

Literature review

The study of attitude and belief change has had a long history. Out of the myriad of approaches a model has developed which incorporates a methodology which allows an exploration of the dynamics of attitude and belief change. The Galileo model, developed by Woelfel and Fink (1980), assumes the definition of any object of cognition (either for individuals or cultures) is given by its location relative to other relevant objects within a multidimensional continuum or space whose properties are determined by the patterns of interrelations among the objects. The global distance between any two objects of cognition or concepts is defined as a belief and the distance between any concept and the self-concept is defined as an attitude. Attitude and belief change is thus modeled as motion of these concepts within the multidimensional continuum. The purpose of the present work is to extend the methodology of the model in order to capture the dynamics of this motion over a time period.

Before a discussion of the methodology, it is first necessary to review the previous literature on the motion of concepts within the multidimensional space. One speculative model of the motion of these objects is derived from the finding that individuals' attitudes tended toward the mean of the attitudes of their significant others (Woelfel and Haller, 1970). Woelfel and

Hernandez (1969) suggest that this finding would be expected if the points in the multidimensional space were to obey Newtons Laws of motion.

A Newtonian model is one in which objects are represented by points in a space, and the functions of positions of the points in time are independent of each other. In the simple model, the space is empty and frictionless, whereas in extended models, empirical coefficients are needed to modify the simple model to conform to cases where gravitational effects, restoring forces, and dissipative forces (like the effects of friction or viscosity) are demonstrated. The model assumes that objects that are associated with each other will approach each other and single objects associated with some set of other objects will approach the geometric center of those other objects. If the space is euclidean then the object will approach the other object or the geometric center of the set of other objects along the straightest line. If the space is curved or riemannian, theory predicts an approach along the geodesic or straightest curve that joins them.

The geometric center is given by the position vector **R**:

$$\mathbf{R} = (r_1 + r_2 = \cdots r_k)/k, \tag{1}$$

where $r_1, r_2, r \cdots rk$ = the position vector of each of the objects in the message; k = the number of objects in the message.

Empirical investigations of the model have usually been in the form of longitudinal measure-treatment-measure design or random assignment to treated or untreated conditions. These are followed by measures of the changes in mean distances observed, and/or correlations of observed motion vectors with the vectors predicted by the theory's equations. The evidence to date, barring one exception, indicate the model shows a good fit to observations. Two studies were done, for example, which showed that the direction of motion of a political candidate closely conformed to the direction of motion predicted for the candidate by equation (1) above (Barnett, Serota and Cody, 1974) and (Serota et al., 1978). In a laboratory experiment manipulating perceptions of public figures and politicians, Cody (1980) showed that the predicted trajectories of candidates associated with other concepts and candidates seemed to correlate highly with the trajectories predicted by equation (1), although some discrepancies are noted (Cody's correlations range from 0.7 to 0.9). Another study consistent with these findings, done by Woelfel, Cody, Gillham, and Holmes (1980), showed that the mean distances among a set of concepts and message sources changed as (1) would predict, with only minor reservations.

The previously mentioned exception to this support of the model is not damaging after a close examination of the specific operationalization used

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An earlier finding by Saltiel and Woelfel (1975) lead to useful extension of the theory in that it supplies further information as to the motion of the objects within the multidimensional continuum. A six-month lagged panel field study in Peoria, Illinois, showed that the generalized American values of 120 high school students demonstrated differential resistence to change over the six-month intervl, and that these inertial properties of the attitudes showed significant relations to the amount of information the students had above the attitudes prior to the onset of the study. Equation (1) above would have to be adjusted should objects prove to be differentially resistant to acceleration, in which case the objects might be expected to move toward the center of the mass of the set of associated objects, rather than toward their geometric center. The adjusted equation is:

$$\mathbf{R} = (m_1 p_1 + m_2 p_2 = \cdots m_k p_1)/(m_1 + m_2 + \cdots m_k), \tag{2}$$

where $m_1, m_2, \ldots m_k$ = the relative masses of the objects.

The inertial mass model was supported by a randomization treatment-measurement laboratory experiment repeated in two independent trials by Danes, Hunter, and Woelfel (1978), in which attitude and belief changes resulting from the treatments were showed to fit the inertial mass model very precisely and better than two plausible alternative models. Barnett (1980), in a study testing the hypothesis that, on the average, the inertial masses of synonyms ought to be proportional to their frequency of occurrence, found support for the model's predictions for three of the synonyms tested.

Woelfel et al. (1980) take the line of research the next step further ant attempted to provide numerical estimates of the inertial masses of common objects in a multidimensional configuration along with estimates of the precision of the masses. Following Mach's notion that inertial masses may be calculated as the inverse of their observed accelerations where acceleration is gauged relative to some frame of reference, Woelfel et al. provide evidence that a stable reference frame within the multidimensional configuration can be established. Once established, Woelfel et al. use a measurement–treatment measurement design and reason that if an attitude or belief is stable and, following some intervention, begins to move, the rate at which it changes its velocity at any instant may be taken as its instantaneous acceleration. The relative masses of the three manipulated concepts were than calculated and it was found that although the evidence seems to support the validity of the notion of inertial mass in the present operationalization, the difference between trajectories predicted by equations (1) and (2) is fairly small compared to current precision of measure, and in any event too small to be reliably determined using the current design.

This does support the notion that objects or concepts do have masses and that these masses may be reliably measured with the existing technology.

Woelfel et al. (1980) point out that in the discussion of experiments like this and others, all calculations depend on the elapsed time between the administration of the stimuli and the measurement of the effect. In order to get a clear picture of these effects it is necessary to make measurements at multiple points in time. Hence, we have reached the stage in this research where the issue at hand becomes the nature of the motion of concepts over some time span. It is critical to monitor both regions of the continuum where some concepts are acted on by some force, and regions of the continuum where concepts are undisturbed. The expectations for the nature of this motion are derived from Prigogine's (1980) theory of Dissipative Structures and from DeBroglie's Equation.

Theory

Prigogine (1980) defines any system that constantly takes in energy/information in order to maintain structure as an open system. A biological structure must constantly take in food in order to maintain itself while a cognitive structure must take in information to maintain itself. Prigogine argues that this constant influx of energy puts the system under constant stress. Prigogine's theory of dissipative structures suggest that open systems, as a result of the constant influx of energy, reach what he calls critical points where the old structure can no longer be maintained under the stress and the system either breaks down or it recrystalizes into a larger more integrated structure and thus a new state/stage of equilibrium or stability. Hence, cognitive systems as open systems would be expected to evolve through successive stages/gestations or break down at specific critical points. Hence, attitude/belief change or motion of objects within the continuum would be

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Prigogine points out that the critical points that open systems reach are infrequent and not completely predictable, hence in the short run, open systems would be expected to behave as equilibrium processes. For our purposes, the motion that cognitive systems act as equilibrium processes would lead to specific expectations as to the motion of concepts once acted upon by some force.

Within the current model, an equilibrium hypothesis would imply that the motion of an object within the system will be governed by basic variables: (a) a force pushing the element out of equilibrium (b) a force restoring the element to equilibrium (c) a position towards which the element "wants" to return (d) the mass of the element (e) the viscosity of the media the element moves in.

The situation of equilibrium can be modeled by a damped harmonic oscillator, which is physically represented by a pendulum or a weight attached to a spring. In its simplest form, the theory suggests that the motion of elements in the multidimensional configuration (attitude and belief change) is governed by these same basic variables that govern the motion of a pendulum or spring-attached weight. The hypothesized relationship is summarized by the equation for damped harmonic oscillators:

$$\dot{m}\dot{x} + k\dot{x} + fx = 0,$$

where a particle of mass, m, is attracted toward the origin (equilibrium position) by an elastic restoring force kx while being acted on by a frictional force fx, which acts in a sense opposite to the velocity, "x" is a generalized coordinate of any kind, a 1/2 $mx(2)$ is the kinetic energy, and 1/2 $km(2)$ is the potential energy. The complex number "x" moves in a logarithmic spiral and the real motion is a simple harmonic motion with exponentially decreasing amplitude. Hence, when acted upon by some external force, we would expect the object to oscillate around some new equilibrium position resulting from the force. Stated formally, the first hypothesis is:

HYPOTHESIS 1: *The magnitude of the distance between the treated concepts when measured over time will oscillate, where the average distance over time represents the new equilibrium distance.*

Measurements along all points within the time period must be made in order to completely test the fit between the data and the equation. This would entail the collection of hundreds of thousands of cases and is beyond the present resources. Therefore, at this exploratory stage what can be done is a qualitative analysis of the macroscopic prediction of the equation, namely that there will be visibly noticeable oscillations among the concepts.

Next is a consideration of the motion of concepts that are undisturbed by external forces. Expectations as to this motion are derived from the finding that concepts exhibit properties of inertial mass and from the addition of the DeBroglie equation to the present model.

The DeBroglie equation described the relationship of inertial mass of objects to their corresponding vibrational rate:

$$m = \hbar v/c \ (2),$$

where m is the inertial mass of the element, v the frequency of vibration, $\hbar$ Plack's constant, and c the velocity of light.

What the equation says is that any object with inertial mass also has a corresponding wave, or vibrational pattern. This finding was crucial in the development of quantum theory in the physical domain, and it is this set of ideas that the present model seeks to test in the cognitive domain. If concepts, as objects with inertial mass, have a corresponding wave or vibrational pattern, i.e., exhibit wave-like properties, then we would expect that concepts that are not disturbed by forces would also exhibit oscillatory motion within the space. Stated formally the second hypothesis is:

HYPOTHESIS 2: *The magnitude of the distance between untreated concepts when measured over time will oscillate, where the average distance over time represents the equilibrium distance.*

What is important to clarify at this stage is that the model has nothing to do with material reality, but describes an abstract process, which "appears" to be similar to attitude/belief change. Much of the discussion thus far has dealt with mathematical descriptions of this process, and these extensions of the model set the stage for a dramatic broadening of the scope of the model. Whether the theoretical extensions are justifiable depends on the extent to which the model fits the process in a measurable way. While a complete test of the model is beyond the scope of a single study, it is feasible to test these predictions in some specific cognitive domain or region of the continuum.

Method

The first step in testing the hypothesis that belief and attitude change might be represented as equilibrium processes is to establish a frame of reference

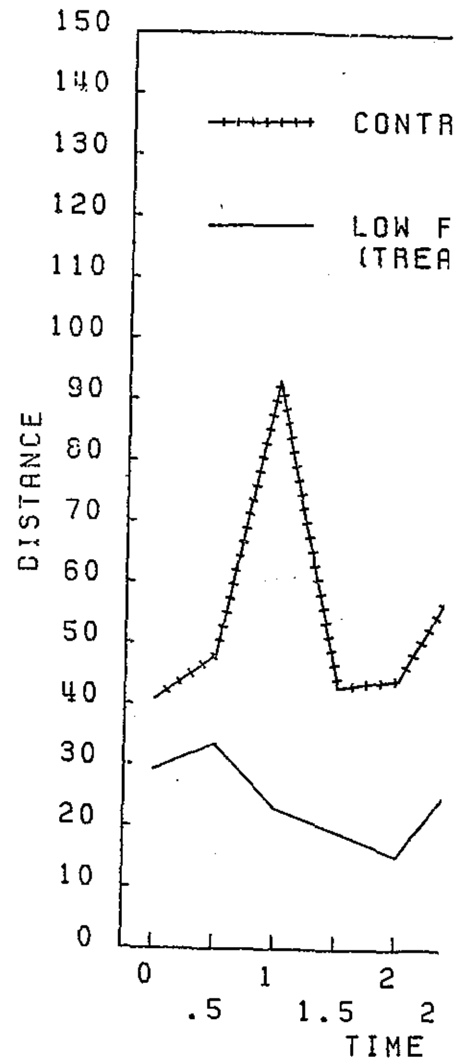

Chart 1. Treatment:

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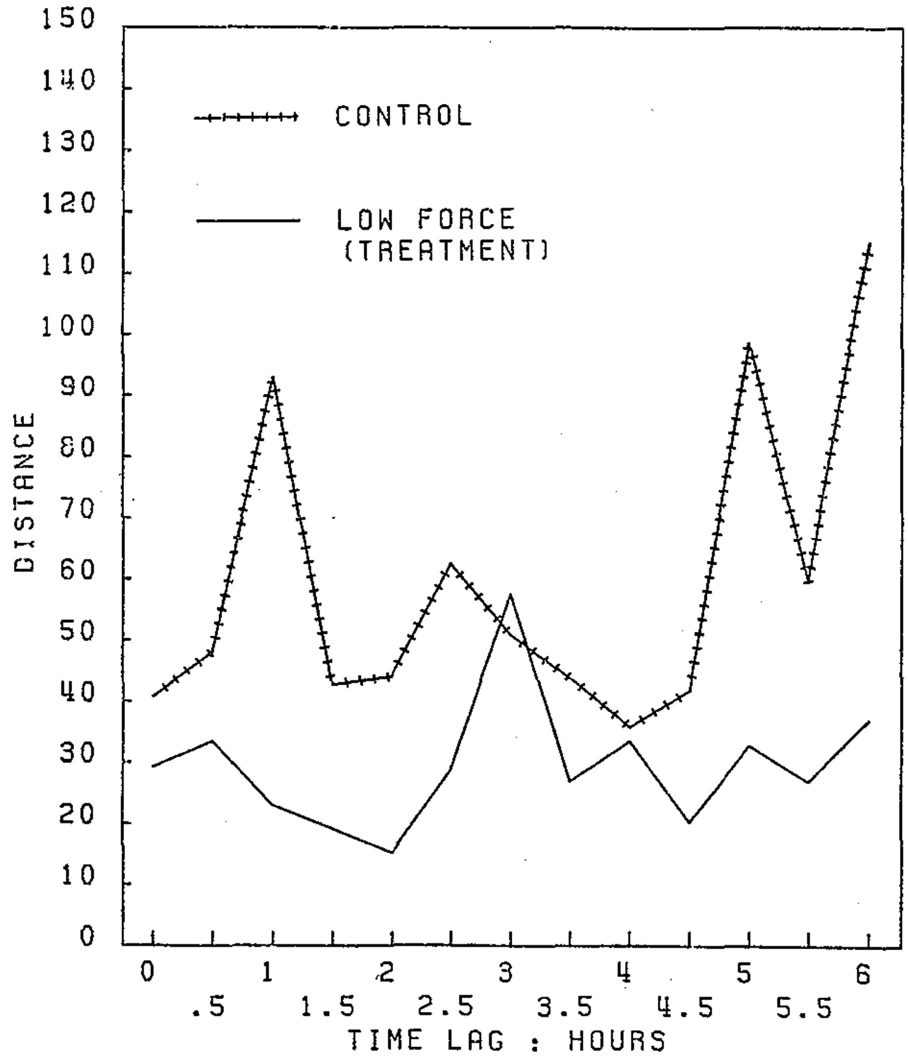


Chart 1. Treatment: low force mean distances.

within which the motions of particular concepts may be gauged. In order to define a relatively stable frame of reference, eight concepts were chosen from a pretest study of the configuration of certain movie stars and attributes. In this pretest it was found that the smallest distance was between the concepts "Jane Fonda" and "intelligent". The largest was found to be between the concepts "Jane Fonda" and "funny". These concepts were chosen to make up the messages in two treatment conditions so as to test the relative impact of using associative messages with concepts of varying degrees of distance, or meaning.

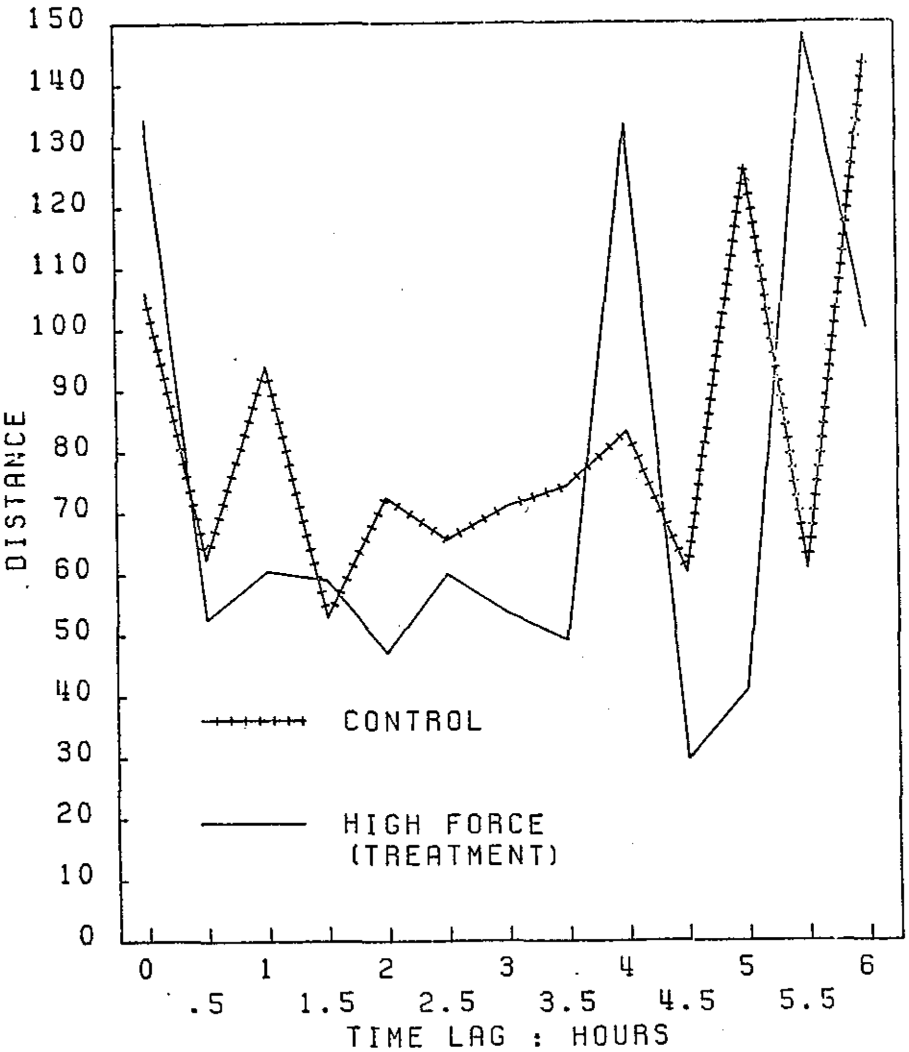
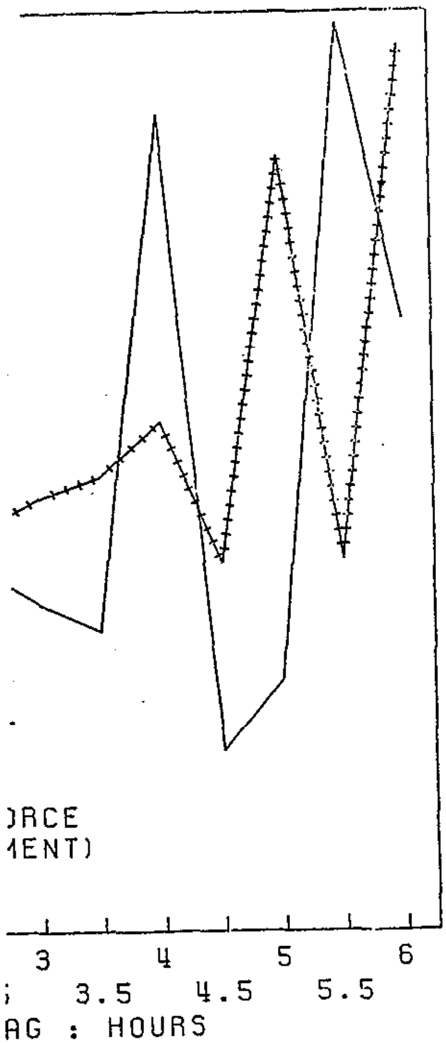


Chart 2. Treatment: high force mean distances.

In a control condition, 400 undergraduate students at the State University of New York at Albany and Buffalo State College read a one paragraph press release suggesting that a fictitious publishing house was about to release a book about movie stars of the seventies which included polls of the public and of the stars themselves. In what was called the "Low force" condition, 400 undergraduates read an identical news release except for the inclusion of a single sentence embedded in the test: "Did you know, for example, that Jane Fonda was considered to be the most intelligent actress

Table 1. Mean distances

Control time	1	2	3	4	5	6	7	8	9	10	11	12	13
Jane – Int.	40.8	48.1	93.0	42.8	44.2	62.6	51.0	43.9	35.9	42.0	98.9	59.8	115.3
Control time	1	2	3	4	5	6	7	8	9	10	11	12	13



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Control time	1	2	3	4	5	6	7	8	9	10	11	12	13
Jane – Funny	106.0	62.5	94.0	53.0	72.5	65.6	71.0	74.3	83.2	60.2	126.4	60.8	184.5
Low force time	1	2	3	4	5	6	7	8	9	10	11	12	13
Jane – Int.	29.3	33.5	23.0	19.2	15.3	28.9	57.7	27.0	33.6	20.4	32.9	29.0	37.1
High force time	1	2	3	4	5	6	7	8	9	10	11	12	13
Jane – Funny	134.3	52.0	60.5	59.0	47.1	60.0	53.5	49.1	133.4	29.6	41.0	148.0	100.1

Table 2. Sum of eigenvalues

Control	1	2	3	4	5	6	7	8	9	10	11	12	13
	17581.2	13384.9	16039.0	8197.7	12326.9	13423.6	16934.3	11260.0	27267.7	12478.2	71182.2	17350.2	28474.0
Low force	1	2	3	4	5	6	7	8	9	10	12	13	
	20646.7	25518.6	18544.9	12425.3	12694.8	13167.6	17293.1	18982.7	28471.3	10157.6	13986.5	11060.7	20307.0
High force	1	2	3	4	5	6	7	8	9	10	11	12	13
	27425.8	18841.7	15143.7	14148.2	75515.8	14948.6	16770.7	7752.1	25298.6	10464.2	10337.9	21951.7	14934.2
Standard error of the estimate control group													
Concept 2,	1	2	3	4	5	6	7	8	9	10	11	12	13
Intelligent	5.6265	1.6956	1.8455	1.8293	1.6352	1.2272	1.2543	1.2875	1.2951	1.0495	1.2603	1.0557	.9456
Concept 2,	1	2	3	4	5	6	7	8	9	10	11	12	13
Funny	5.3843	1.7629	1.6442	1.8509	1.6063	1.5030	1.2927	1.2694	1.3428	1.1075	.6654	1.0358	1.0762
Concept 2,	1	2	3	4	5	6	7	8	9	10	11	12	13
Jane Fonda	6.7949	4.8119	2.4754	2.2464	1.9048	1.3424	1.5571	1.5827	1.3439	1.3475	1.0861	1.2170	9511
Low force													
Concept 2,	1	2	3	4	5	6	7	8	9	10	11	12	13
Intelligent	3.3370	3.1758	2.4589	2.3917	2.0767	1.9804	1.6403	1.5496	1.5302	1.3878	1.4191	1.2681	1.2583
Concept 5,	1	2	3	4	5	6	7	8	9	10	11	12	13
Jane Fonda	9.5854	5.6164	3.0989	2.4700	2.6835	2.0908	1.9278	1.8115	1.6962	1.3240	1.6057	1.4484	1.3969
High force													
Concept 3,	1	2	3	4	5	6	7	8	9	10	11	12	13
Funny	8.0656	2.6458	2.0185	2.3201	2.1784	1.9191	1.8782	1.7097	1.4629	1.5769	1.5343	1.2194	1.3407
Concept 5,	1	2	3	4	5	6	7	8	9	10	11	12	13
Jane Fonda	8.5143	2.7838	2.7071	2.3054	4.3490	2.3415	1.7752	2.0840	1.6510	1.8046	1.7825	1.4723	1.4951

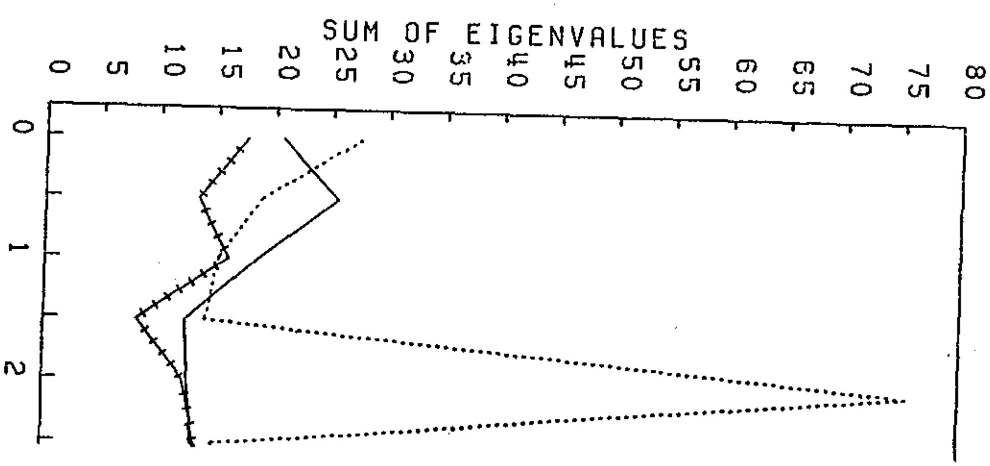

Chart 3. Sum

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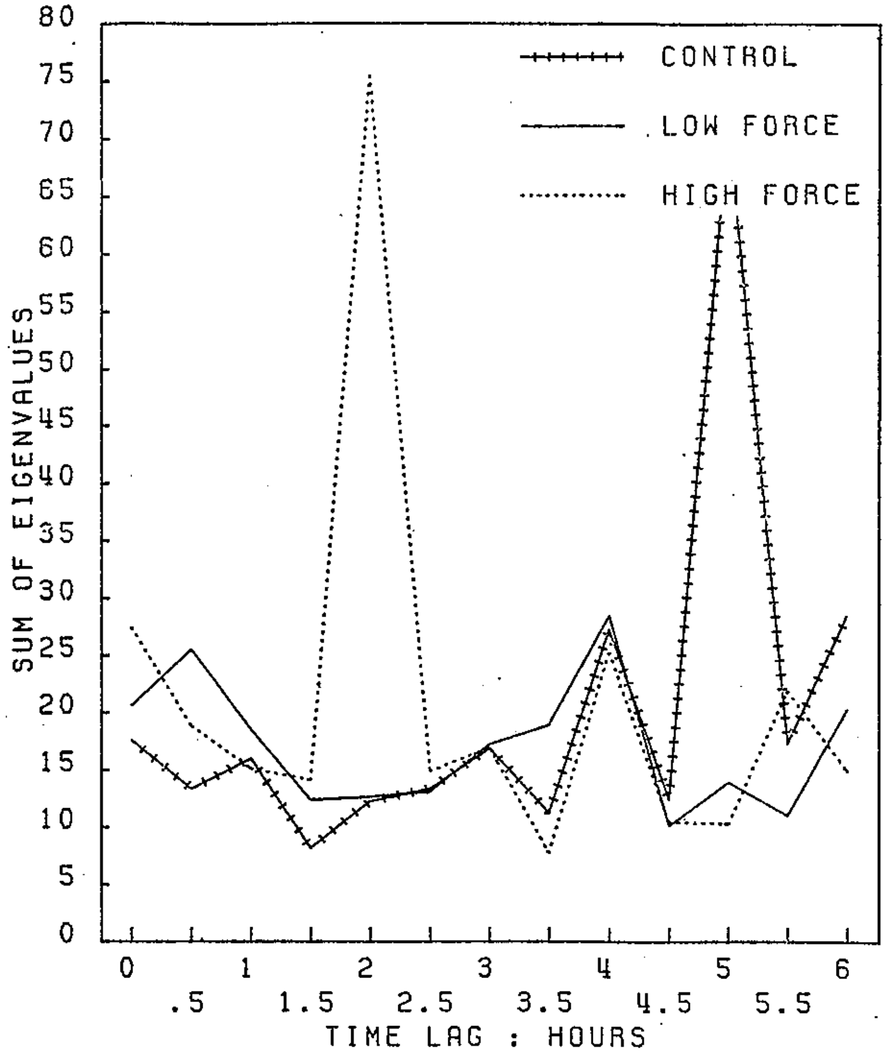

Chart 3. Sum of eigenvalues.

of the seventies?", (the condition was called Low force in reference to the concepts potential motion as a result of an associative message,). In the "high force" condition, where the potential motion or existing discrepancy of meaning between concepts was greater, 400 undergraduates read an identical news release except for the inclusion of the sentence, "Did you know, for example, that Jane Fonda was considered the funniest actress of the seventies?".

All respondents were randomly assigned to one of thirteen time lags, starting from immediately after reading the message and then increasing in

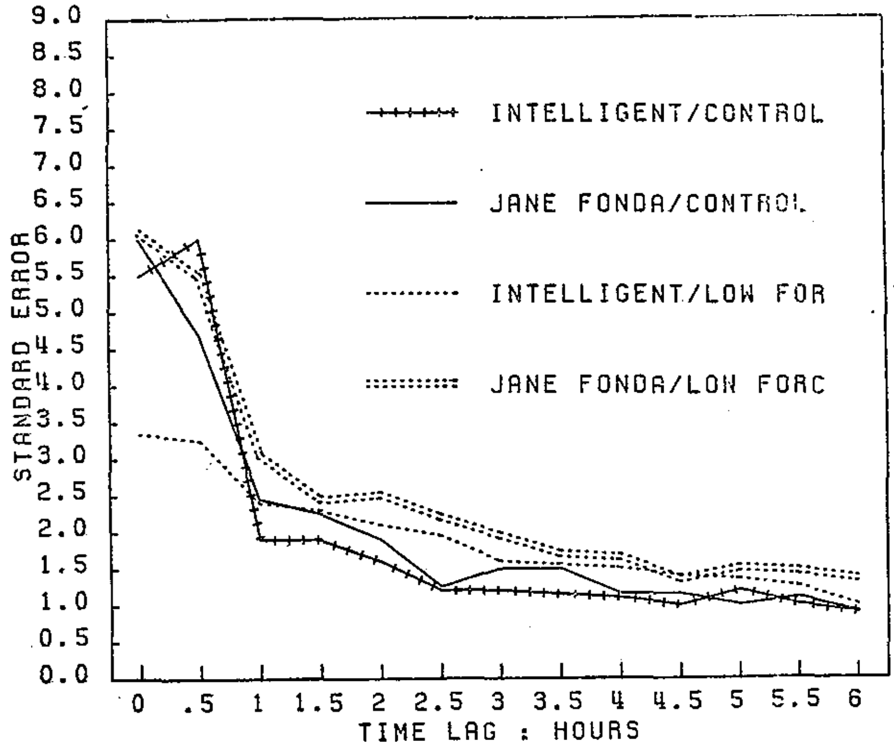

Chart 4. Standard error: low force.

half hour increments up to six hours after reading the message. According to what time lag was assigned, each respondent would fill out at that time a Galileo type complete paired comparison questionnaire on which they estimated the dissimilarities among the pairs of movie stars and attributes relative to an arbitrary standard which suggested that the concepts "funny" and "sex appeal" are 100 units apart (i.e. these two concepts differed in meaning by 100 units).

These data were entered into the Galileo version 5.2 at S.U.N.Y. albany for analysis. Each of the thirteen spaces generated from the data sets of each of the two treatment groups and the control group were rotated to a weighted least squares best fit to the space previous in the time lag series. In the treatment groups, the concepts "Jane Fonda", "intelligent", and "funny" were set as free concepts which causes the program to rotate all concepts, but to measure least suares goodness of fit against only the stable concepts. Choosing this pattern of options is equivalent to fixing the stable concepts as a set of reference points against which the relative motions of these three free concepts may be gauged. In a sense, the program generated

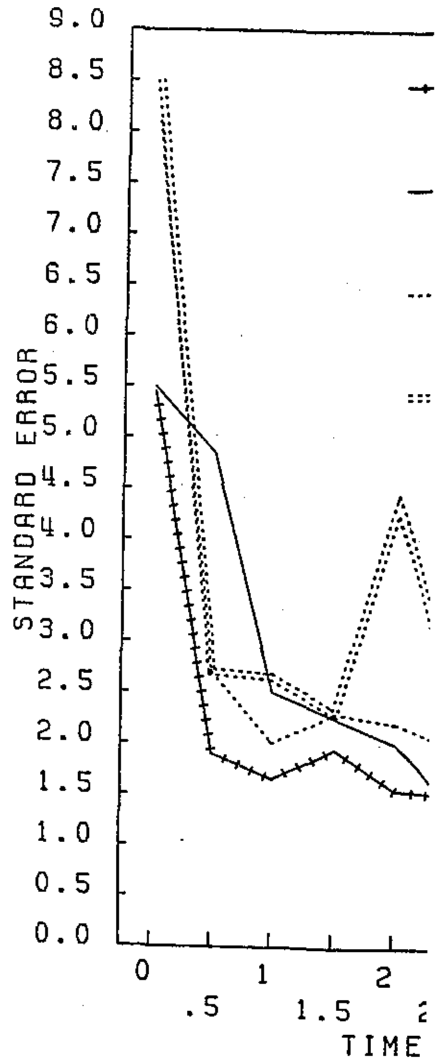

Chart 5. Stand

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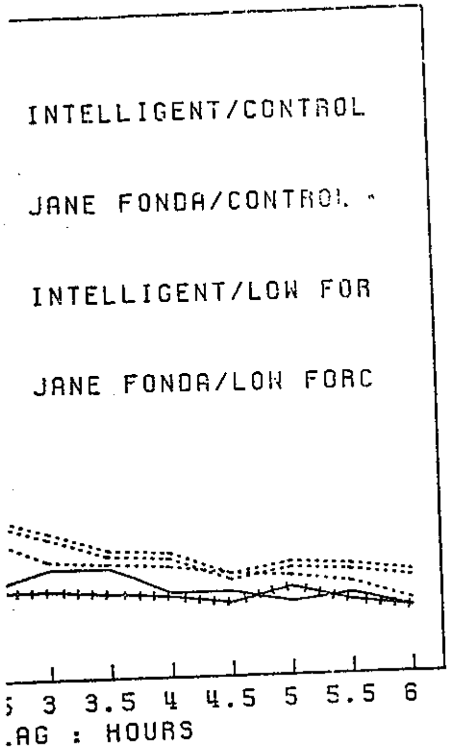

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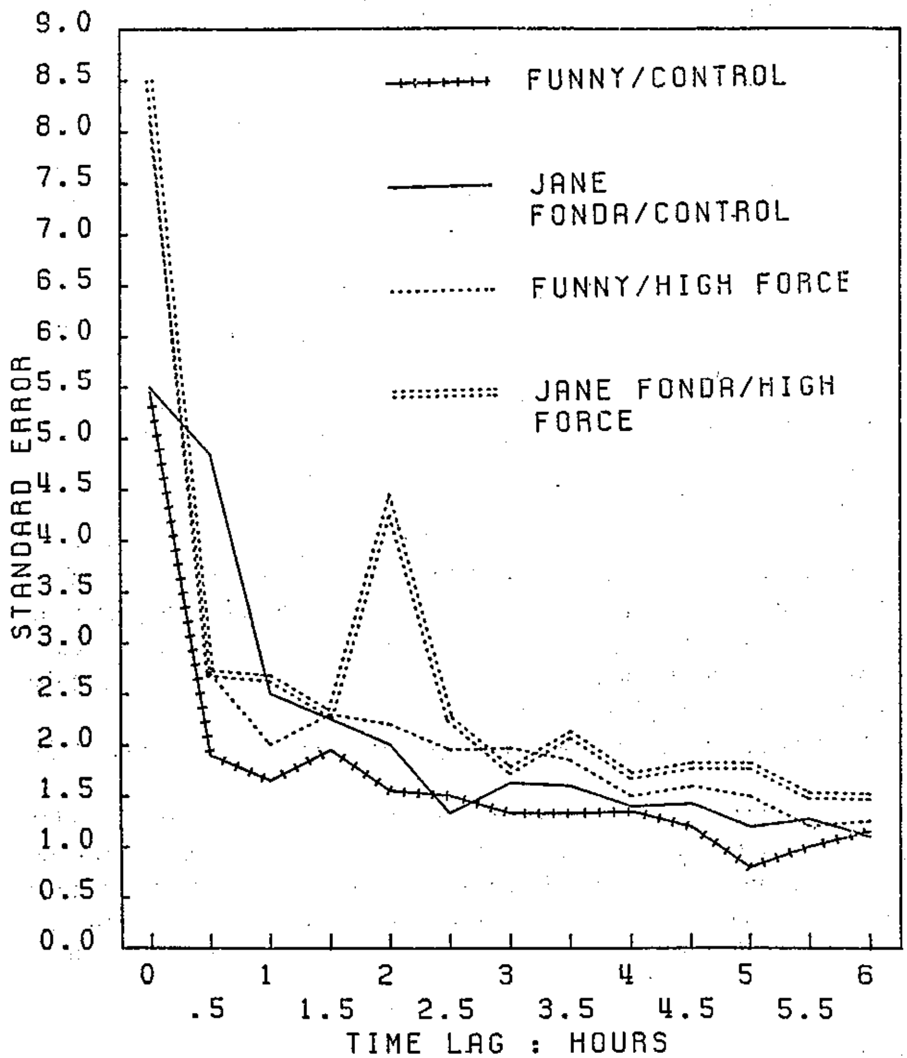

Chart 5. Standard error: high force.

three sets of thirteen consecutive snapshots of the motion of eight concepts over a six-hour period, the first motion pictures of change in cognition.

Results

Visual scrutiny of the plots of the mean distances indicate that the treatment induced change for both the Low force and high force treatment groups (see

Charts 1 and 2). Over the thirteen time periods, the mean distance between the concepts "intelligent" and "Jane Fonda" was on the average 36 units smaller in the Low force condition than the control condition, while the mean distance between the concepts "funny" and "Jane Fonda" was on the average 21 units smaller in the high force condition than the control conditional. The plots indicate oscillations in the distances throughout the six hour period for both treatment groups and the control group, supporting the predictions of the DeBroglie equation. The graphs do not reveal any relative difference in pattern or intensity in oscillation between the control or Low force condition, however the high force condition reveals an oscillatory pattern of an apparently erratic nature. The pattern seems to describe a system in "chaos", similar to the pattern of motion that describes a system in "chaos", similar to the pattern of motion that describes a shock absorber taking the shock of a deep pot-hole, i.e. a system temporarily pushed beyond the range of equilibrium.

The plots of the sum of eigenvalues (see Chart 3) reveal no significant difference between treated and untreated conditions in the overall size of the space or in the intensity of oscillations. The plots indicate an approximate similarity in the pattern of oscillation in the sizes of the space generated. apparently, the treatment had no discernable effect on the overall size of the space or the pattern of oscillation.

Another interesting finding turned up in the analysis of the plots of the standard error of estimate (see Charts 4 and 5). Although there was a gradual decrease in the standard error from time periods 3 through 13 for all groups (on the average moving from 2.5 to 1.5), there was a dramatic decrease from period 1 through 3. The drop was even more dramatic in the high force group, starting at 8.9 and dropping to 3.0 At period 3 apparently, the hour time lapse had some effect on respondents efficiency of estimation.

Discussion

The hypothesis that attitude and belief change can be represented as equilibrium processes can only be addressed by a comprehensive research program that allows comparison of numerous data sets from numerous domains. While this pilot study does offer some interesting insights as to the nature of the motion of elements within the continuum, we have not yet come to grips with some methodological issues, specifically the establishment of standards of measure, that would allow a determination of an equilibrium state and the extent of the dampening. However, we have made advances with regard to the establishment of reference frames and through

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use of random assignment to time lags. These advances allow preliminary glimpses of the dynamic process of cultural change.

An important finding which has implications on the visual conceptualization of the model is the finding of oscillatory patterns in both the treatment and control groups. The findings imply that the model might be visualized as conceptual points in a multidimensional cognitive space whose element move not only when acted upon by the force of a message, but also exhibits vibrational or oscillatory motion over time. This conceptualization is exciting in that it seems consistent with recently developed theories in physics and neurophysiology (Pribram, 1978 and Bohm, 1980), which view ideas as patterns of vibrating energy. These conceptual bridges between disciplines engaged in the study of cognitive consciousness are the first steps towards the synthesis of social and physical science. As stated earlier, the addition in conceptualization allows an exploration of phenomena associated with attitude and belief change that have not traditionally been investigated by social science. It is only through synthesizing methodological approaches and communicating across disciplines can science hope to make the breakthroughs it strives for.

One of the more intriguing findings is the dramatic drop in the standard error of estimate over the first hour of time lag. Speculation would point towards the possibility of messages causing a "jolt" in the structure (and thus a high standard error) which decays over theperiod of approximately an hour. It may be that the less "plausible" the message, the more the severe the jolt, as evidenced by the finding that the high force condition, (which contained the relatively less plausible message "Jane Fonda is . . . considered funny . . ."), showed a substantially higher standard error over the first hour period. Even the control group had a similar decay which implies that reference to a cognitive domain will cause a "jolt" throughout that domain. Experiments can be designed to further test these notions.

This pilot study, as with most studies, begs certain questions: Will there be differences in oscillatory patterns among treated and non-treated conditions in other domains of meaning? This study found no difference in the patterns over time of the eigenvalues or mean distances for the Low forces and control condition, yet for the high force condition the pattern of mean distances appeared to reflect a system in "chaos". Further studies varying the cognitive domain and message plausibility must be done in order to establish general hypotheses as well as to determine if the currently available equations that describe systems out of equilibrium can be used to account for this kind of cognitive motion. Another question is whether patterns of oscillation can be mapped to the point where information could be gleaned as to the timing of messages. It may be that messages that are presented at a moment where the concept has oscillatory motion in a direction consistent with the target position would have a more powerful impact that when the concept is moving against the momentum. Again, studies may be designed which would serve a great value to those who mount persuasive campaigns.

Another issue which this study brings in to discussion is the exact nature of these oscillatory patterns. To fully explore the moment to moment changes in the positions of concepts one must make as many measurement as one can, as close together in time as one can. Research is currently being conducted along these lines in order to address this issue and others, such as the extent to which oscillations are quantum or contiguous, or the extent to which patterns of interacting systems oscillate in phase. The present findings encourage further inquiry along these lines.

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Quality & Quantity 24: 17–36, 1990.

Inducing relations on incomp

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Abstract. Let X denote a set of n elements o
L based on some attribute of comparison. I
form of a partial order P on X. This study
reconstruct, L based only on the ordinal inf
ing this problem are the cardinal and sequel
for the expected error of weak order app
construction methods. Results involving in
sidered. Previous simulation comparisons f
interval orders were found to depend on the
interval orders, and were not found to hold
the likelihood that any particular linear ext

1. Introduction

Let $X = \{x, y, \ldots\}$ denote a set
underlying linear ranking L based c
pairwise comparison, xLy is inte
the attribute in question than does
order, it is asymmetric ($xLy \Rightarrow$ no
$yLz \Rightarrow xLz, \forall x, y, z \in X$), and com
We suppose that incomplete but ac
ordering of the elements of X in
incomplete information is given in t
means that P is asymmetric and tra
to be correct, so that $P \subseteq L$.

The purpose of this study is to co
or reconstruct, the underlying line
information contained in the data
develop in a number of different pr
that X represents a set of brands
consumer's preference ranking on
might attempt to obtain L from th
preferences of a consumer on bran