Theory and Observation in Cultural Transmission

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$\delta^{13}C =$
$$\frac{^{13}C/^{12}C_{sample} - ^{13}C/^{12}C_{standard}}{^{13}C/^{12}C_{standard}} \times 1000$$
relative to the Pee Dee belemnite standard (PDB-1).
$\delta^{18}O =$
$$\frac{^{18}O/^{16}O_{sample} - ^{18}O/^{16}O_{standard}}{^{18}O/^{16}O_{standard}} \times 1000$$
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Theory and Observation in Cultural Transmission

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The activities, values, and behavior of an individual that are acquired through instruction or imitation will be termed "cultural." Such phenomena are not exclusively human (*1*) but are most highly

Summary. Cultural phenomena may show considerable stability over time and space. Transmission mechanisms responsible for their maintenance are worthy of theoretical and empirical inquiry; they are complex and each possible pathway has different effects on evolutionary stability of traits, as can be shown theoretically. A survey designed to evaluate the importance of some components of cultural transmission on a variety of traits showed that religion and politics are mostly determined in the family, a mode of transmission which guarantees high evolutionary stability and maintenance of high variation between and within groups.

developed in our species. In attempting to construct a quantitative theory for the evolution of cultural traits we have found many concepts from the quantitative theory of biological evolution to be useful (*2*). It has often been suggested (*3*), though not widely appreciated, that the evolution of cultural phenomena can be viewed in a conceptual framework similar to that of biological evolution, but so far most analyses have been purely qualitative.

That the continuing process of evolution by random mutation and natural selection has produced the complexity and diversity of living systems is the cornerstone of interpretation in the biological sciences. Observed genetic variation is the result of interactions between the rules of genetic transmission, mutation, natural selection, and sampling, due to the finiteness of natural populations. Each of these phenomena can, in principle, be measured, and together they allow statistical prediction of the evolutionary trajectories of the genotypes in the population.

The cultural analog of mutation includes innovation as well as random change in the expression of traits (*2*). In fact, Galton (*4*), in explaining biological mutations ("sports" in domesticated plants and animals) compared them to technological innovations. Our concern here is not with the comparison of mutation and selection in biological and cultural situations, but with another ingredient in the process of evolution—transmission. Although well studied and quantified in biology, transmission is poorly understood in its cultural context. The study of quantitative aspects of cultural transmission can, we believe, create a foundation for the study of cultural evolution and, in the quantitative theoretical development upon which we have embarked, modeling of cultural transmission has a central place (*2*). To date quantitative studies of cultural transmission have been limited, although there already exist theories, such as mathematical epidemiology (*5*), which could augment the study of diffusion of innovations (*6*). In this article we suggest some of the possible applications of our general theory, in an empirical investigation of quantitative aspects of our general theory.

Models of Transmission

Cultural transmission is the process of acquisition of behaviors, attitudes, or technologies through imprinting, conditioning, imitation, active teaching and learning, or combinations of these. A quantitative theory of the evolution of a culturally transmitted trait requires modeling who transmits what to whom, the number of transmitters per receiver,

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their ages, and other relations between them.

As a first step in measuring cultural transmission it is natural to consider discrete valued traits and the parent-offspring relationship. When the transmission is from parent to child it is termed vertical, in agreement with usage in epidemiology, and the natural discrete time unit is the generation. We use horizontal transmission to mean transmission between members of the same generation, and oblique for transmission from nonparental individuals of the parental generation to members of the filial generation. In what follows horizontal transmission is considered in the restricted context of age peers. Transmission from, for example, teachers or mass media has been modeled in our theoretical studies (*2*).

Just as in population genetics, ecology, and epidemiology, the dynamical studies of these models can point to situations in which heterogeneity (polymorphism) might reasonably be expected to be maintained within a population. In addition, the use of models allows comparison of rates of evolutionary change in terms of mode of transmission. For example, oblique transmission through teachers increases homogeneity within a population and creates greater variation between populations in space and time than does vertical transmission (*2, 7*).

Some broad principles have emerged from our theoretical work and can be applied to situations in which a fixed level of cultural mutation is present with respect to one specified cultural trait. If the number of transmitters per recipient is many-to-one, the rate of evolution (change of trait frequency with time) is slow, and variation within and between populations is low. An example is oblique transmission through social class or caste stratification in which many transmitters, potentially even the whole group, apply the same cultural pressure on each of the individuals in the next generations. This is a conservative mode of cultural transmission. If, as in the case of a teacher, transmission is one-to-many, cultural change is expected to be rapid and within-population variation low. The intermediate situations of one-to-one or one-to-few transmission (as in parent-to-child or -children transmission) produce moderate rates of change and relatively high within- and between-population heterogeneity (Fig. 1). A specific trait may, of course, be transmitted in more than one way by mechanisms whose actions may not always be in concert.

Table 1. Agreement of repeated observations on the same individual: correlation between ratings of an individual by different observers (including self) in the six major categories of traits (listed in Table 5). Values are the means and ranges of correlations averaged among all possible pairs of observers.

Category	Correlation (r)	
	Average	Range
Religion	.72	.42 to .87
Sports	.58	.48 to .83
Politics	.50	.22 to .77
Entertainment	.35	.18 to .57
Habits	.32	.12 to .51
Beliefs	.17	.05 to .37

Such generalizations about rates of cultural evolution also depend on the time units involved. For parent-child transmission the biological generation is a natural time unit, but for the transmission among age peers the time unit is shorter and the rate of change is correspondingly increased. Alternatively, cultural change is retarded when grandparents, elders, or oral and written traditions play key roles in the determination of trait values (*2, 7*).

Survey Approach to Cultural Transmission

We summarize an analysis of data whose collection was suggested by the theory of cultural transmission and which may prove to be more generally useful in describing the importance of the family in cultural transmission.

There have been many studies of the influence of parents on children in relation to political preferences (*8*), attitudes toward authoritarianism (*9*), religiosity (*10*), and other attitudes, beliefs, and behaviors. But a number of these studies have been criticized (*11*) for mode of sample collection, poor assessment of reliability, and lack of emphasis on group correspondence.

For this study we distributed a questionnaire to Stanford University undergraduates, mostly sophomores and juniors who were enrolled in courses required either for the biology or human biology major. The questionnaire was designed to sample a variety of cultural traits in six categories: (i) religious affiliation and attitudes, (ii) political affiliation and attitudes, (iii) entertainment, (iv) beliefs about some contentious issues (including superstitions), (v) habits that are easily described without invasion of privacy, and (vi) sports. Some questions required answers of yes or no; others required assignment to positions on a scale (for example, a frequency scale with answers such as more than once a day, once a day, once a week, and so on) and were later dichotomized (*12*).

Students answered the same questions in the six categories about themselves, their fathers, mothers, and one male and one female friend (*13*). In addition, students reported their sex, occupation of parents, and an estimate of parental income. Students also received questionnaires to mail or hand to parents and the friends about whom they had answered along with a letter explaining the project. Parents and friends were asked to answer the same questions about themselves and the students that the students had answered. All questionnaires were linked numerically to preserve anonymity.

Only sets of questionnaires returned by a student and both parents ($N = 203$) or by a student and both friends ($N = 98$) were analyzed. About 53 percent of parental pairs returned the questionnaires; the return from both friends was 40 percent. Preservation of anonymity precluded sampling of nonrespondents. These response rates are moderately high when compared to similar studies (*8–11*).

Agreement of Ratings

Each student was evaluated by either three individuals (self and two parents or self and two friends) or five individuals (self, two parents, and two friends) (*13*). Parents and friends were rated by themselves and by the student. There were therefore at least two evaluations for each participant. The correlation between ratings of the same person by different people (one of whom was self) was used as a measure of agreement between observers.

Correlation coefficients (r) indicating agreement for a given trait were averaged after grouping the traits into the six major categories (Table 1). Moreover, for each trait many agreement values were calculated and averaged, as explained below. The variation between the correlations averaged is expressed by their ranges. Agreements spanned almost the whole range between zero and one (Table 1). The ranges of agreement for the various groups of traits (which are listed individually in Table 5) show that agreement decreased in the following order: religion > sports > politics > entertainment > habits > beliefs (Table 2).

There were a number of correlations, all indicating agreement between different observers rating the same individual for a given trait. Parents were rated by themselves and their children (not by the other parent, because of possible parental separation). Thus there is a correlation coefficient for father rated by self and father rated by child, and another similar correlation for mother. For child rated by father (or mother) and by self, there are three possible correlations. For each of the two friends (of different sexes) there were ratings by the student and by self, generating two other correlations (one for each friend). Altogether, there were seven correlation coefficients measuring agreement of ratings of the same person by different observers, two for the rating of parents, three for students, and two for student's friends.

There is a trend in the agreements according to the relationship of observer and observed (not shown in Table 1). Agreement between ratings of the same person by different people (including self) was highest when the subject observed was one of the parents (r = .45, with a large standard deviation between traits, ±.23), less when students were scored by parents or by themselves (r = .41, ±.20), and least when students and friends were rating each other (r = .33, ±.18). In part the differences in agreement may be due to the different periods of life of the observers. In part they may be due to error, but biases, observer-observed interactions, and deficiencies of the survey instrument cannot be excluded. Reliability, as indicated by the coefficients of agreement, affects the confidence to be placed in the results discussed below, especially for certain traits.

Correlation Analysis

Our primary interest is the degree of similarity between parent and child, between parents, and between friends. Thus, observations were first analyzed by standard correlational methods. Self-ratings gave values for the target correlations that were generally smaller than those computed from observers other than self (*14*), but the differences were not usually statistically significant. We were conservative and used self-ratings in evaluating these relationships.

Table 2 summarizes the correlations that express overall similarities of interest in the six categories. The order of correlations for traits averaged for each category is similar to that for agreement; for the three sets of observations the order is: (i) parent-child, religion > politics > entertainment > sports > beliefs > habits; (ii) father-mother, religion > politics > sports/entertainment > beliefs > habits; and (iii) friend-friend, religion > sports/politics > entertainment/beliefs > habits (*15*). Similarities and agreements correlate highly, at least in family groups (r = .76 for parent and offspring, .81 for father and mother, but only .38 for friend and friend). These correlations suggest that because of the low agreement for certain traits the true similarity may be higher than that estimated by the raw correlation.

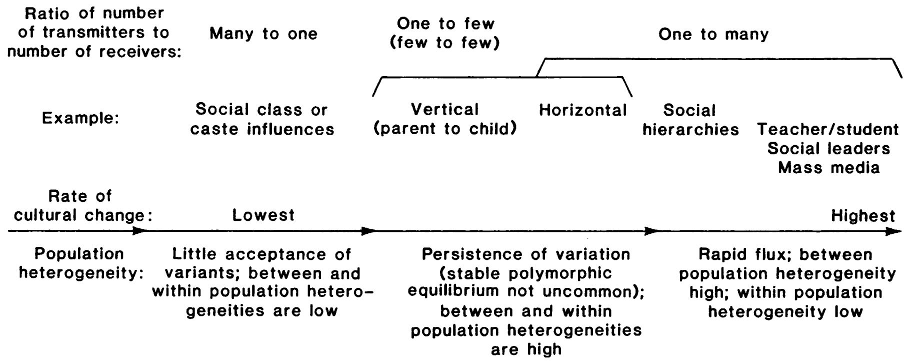

Fig. 1. Modes and rates of cultural transmission.

Table 2. Means and ranges of correlation coefficients by category for various pairs; self-ratings only were used.

Category	Correlation (r) between responses of: Father-mother Average	Father-mother Range	Parent-child Average	Parent-child Range	Friend-friend Average	Friend-friend Range
Religion	.69	.42 to .91	.57	.33 to .82	.20	.10 to .34
Politics	.48	.37 to .57	.32	.09 to .52	.16	.10 to .27
Sports	.34	.16 to .54	.13	.04 to .20	.16	.0 to .34
Entertainment	.30	.08 to .58	.16	.02 to .29	.10	−.02 to .24
Habits	.17	.04 to .47	.07	−.02 to .21	.05	−.25 to .22
Beliefs	.11	.11 to .36	.09	.06 to .12	.12	.03 to .21
General average	.35		.22		.13	

Table 3. Means of disattenuated similarities by category for various paired responses (*16*).

Responses	Correlation (r): Religion	Sports	Politics	Entertainment	Habits	Beliefs
Father-mother	.83	.49	.79	.74	.49	.99
Parent-child	.71	.22	.61	.44	.24	.49
Friend-friend	.31	.33	.49	.30	.26	.68

Table 4. Additive model of vertical transmission. The b_i's are proportions of type H individuals in progeny of the four types of parental pairs. In the last three columns is the numerical example of Democratic party affiliation.

Additive model: Father	Mother	Frequency of pair	Transmission coefficient	Expected values of b_i	Example: Democratic party affiliation: Number of parental pairs	Observed H offspring (%)	Expected offspring (%)*
h	h	p_0	b_0	β_0	99	25	27
h	H	p_1	b_1	$\beta_0 + \alpha_M$	27	74	68
H	h	p_2	b_2	$\beta_0 + \alpha_F$	14	64	51
H	H	p_3	b_3	$\beta_0 + \alpha_F + \alpha_M$	55	91	92

*For β_0 = .27, α_M = .41 and α_F = .24, estimated by maximum likelihood; goodness of fit: $\chi^2(1)$ = .72, P > .20.

Table 5. Survey of nuclear family data. The traits tested by the questionnaires on Stanford University students were dichotomized as positive or negative (H or h). Transmission data in the first four numerical columns are the b_i values—that is, the percentage of H progeny from the given parental pair (father × mother). The numbers of parental pairs correspond to the absolute frequencies of the p_i values (see Table 4). *F*, frequency.

Trait	Vertical transmission: Progeny H (%)				Vertical transmission: F × M pairs (*N*)					Paternal transmission†					Maternal transmission†					Goodness of fit (χ^2)‡		*IVT*
	h × h	h × H	H × h	H × H	h × h	h × H	H × h	H × H	*P**	r_{FC}	*P*	$r_{FC\cdot M}$	*P*	α_F	r_{MC}	*P*	$r_{MC\cdot F}$	*P*	α_M	Additive	Log-linear	
Religion																						
R 1 Attend church (*F*)	21	37	29	65	96	30	7	69	3	.37	3	.19	2	.24	.36	3	.17	1	.20	.93	.62	.48
R 2 Pray (*F*)	19	57	20	68	52	53	10	87	3	.25	3	.09		.09	.41	3	.35	3	.40	.38	.22	.64
R 3 Catholic	1	75	0	81	150	8	2	27	3	.70	3	.05		.00	.04	3	.64	3	.79	.11§	.04	.92
R 4 Jewish	1	0	0	80	158	1	3	25	3	.78	3	.14	1	.00	.81	3	.40	3	.76	1.71§	.95	.89
R 5 Protestant	4	53	8	63	89	19	12	67	3	.44	3	.07		.06	.60	3	.46	3	.52	.16	.04	.87
Politics																						
P 1 Registered voter	50	67	100	83	6	9	8	179		.16	1	.17	1	.24	.03		−.04		.00	2.13§	3.02	.27
P 2 Registered with party	25	40	44	72	28	25	18	130	3	.33	3	.24	3	.27	.29	3	.18	1	.21	.46	.33	.61
P 3 Democratic	25	74	64	91	99	27	14	55	3	.48	3	.24	3	.24	.55	3	.38	3	.41	1.72	.23	.49
P 4 Republican	5	27	14	47	77	15	29	74	3	.34	3	.14		.11	.42	3	.30	3	.29	.63	.03	.79
P 5 Conservative	11	8	35	62	18	13	17	150	3	.36	3	.28	3	.42	.27	3	.12		.11	3.07	1.24	.86
Sports																						
S 1 Swim (*F*)	29	42	58	65	141	24	19	17	2	.24	3	.20	2	.27	.16	1	.09		.11	.09	.10	.20
S 2 Tennis (*F*)	39	44	59	61	132	18	17	33		.18	1	.14		.18	.12		.03		.04	.03	.03	.10
S 3 Jog or run (*F*)	48	61	57	47	124	18	46	15		.04		.03		.04	.03		.02		.04	1.45	1.45	.04
Entertainment																						
E 1 Watch TV (*F*)	67	33	57	54	6	9	7	179		.04		.06		.12	−.04		−.06		−.13	.91	.88	.01
E 2 Listen classical music (*F*)	41	57	45	71	37	30	20	115	2	.19	2	.10		.11	.24	3	.18	2	.21	.36	.43	.38
E 3 Watch football (*F*)	36	64	63	66	42	11	82	68	2	.21	2	.19	2	.21	.12		.07		.07	1.85	1.76	.32
E 4 Watch baseball(*F*)	25	38	56	65	60	13	64	66	3	.32	3	.28	3	.30	.19	2	.10		.10	.07	.12	.47
E 5 Like to camp	80	100	81	90	30	6	27	40	1	.11		.01		.00	.27	2	.24	1	.17	.20§	.30	.09
E 6 Like to visit art museums	57	61	100	79	7	18	5	76		.20	1	.21	1	.26	.00		−.06		−.18	1.33	1.98	.05
E 7 Like big parties	26	38	67	63	35	26	18	27	2	.33	3	.32	3	.32	.11		.06		.06	.75	.79	.38
E 8 Attend movies (*F*)	63	85	80	96	145	13	15	28	3	.23	3	.11		.14	.25	3	.14	1	.19	.12	.71	.10
E 9 Like adventure movies	48	62	48	64	48	13	66	55		.04		.01		.01	.15	1	.14		.15	.01	.01	.11
E10 Like light movies	100	91	78	91	8	23	23	128		−.06		−.07		−.04	.08		.09		.06	2.87	2.39	.03
E11 Like serious movies	20	86	100	87	5	35	10	132	2	.12		.12		.08	.11		.10		.09	1.16	10.20	.17
Habits																						
H 1 Salt use high	26	65	36	60	99	17	67	20	2	.10		.07		.07	.26	3	.25	3	.31	.66	.73	.25
H 2 Routinely check bill	52	63	67	71	48	32	49	73		.14		.12		.12	.09		.07		.06	.21	.16	.16
H 3 Morning/evening person	67	78	73	72	3	18	15	69		−.03		−.03		−.04	.01		.01		.01	.16	.16	-0.02
H 4 Like coffee	83	41	85	59	6	17	13	69		.10		.12		.13	−.22		−.24		−.29	.51	.20	-0.21
H 5 Like tea	100	69	44	78	3	16	9	78		.01		.00		.02	.13		.13		.18	4.53	4.56	.24
H 6 Milk with dinner (*F*)	67	53	56	69	66	15	9	16		.00		.02		.02	−.04		−.04		−.05	1.18	1.17	-0.01
H 7 Last-minute person	46	59	36	63	50	17	28	8		−.07		−.07		−.07	.15		.15		.17	.34	.34	.03

H 8 Like big breakfast	45	33	64	71	29	9	33	34		.24	1	.23	1	.25	.08		.02		.02	.71	.72	.28
H 9 Many close friends	15	20	0	57	82	15	1	7		.24	1	.17		.29	.18		.08		.08	1.28	1.10	.23
H10 Good correspondent	45	48	39	47	44	25	18	17		−.03		−.04		−.04	.04		.04		.05	.07	.07	.00
Beliefs																						
B 1 Read horoscope (*F*)	31	55	45	50	104	55	20	24	1	.07		.04		.05	.20	2	.19	2	.19	1.22	1.28	.22
B 2 UFO's	51	56	68	68	75	48	25	41		.15	1	.14		.14	.07		.04		.04	.12	.10	.12
B 3 ESP	76	57	71	84	17	37	7	133	2	.22	2	.23	2	.21	.03		−.06		−.03	2.60	2.11	.16
B 4 Lucky numbers	21	42	19	29	136	24	27	14		−.02		−.05		−.04	.15	1	.15	1	.17	.38	.25	.12
B 5 Ability versus luck	29	28	29	48	91	36	45	29		.08		.08		.07	.08		.07		.07	1.90	1.76	.14
B 6 Jogging for health	71	81	79	81	59	37	43	62		.06		.05		.04	.08		.06		.05	.48	.41	.06
B 7 Margarine or butter for health	27	45	41	55	10	47	17	96	1	.16	1	.11		.11	.18	2	.14		.16	.04	.07	.39

*Significance (*P*) of evidence for transmission determined from χ^2 values with 3 degrees of freedom of 4 by 2 contingency tables formed by data in first eight columns: 1, significant at $P < .05$; 2, significant at $P < .01$; 3, significant at $P < .001$. †Analysis of paternal and maternal transmission: r_{FC} and r_{MC}, raw correlations between father (F), or mother (M), and student (C); $r_{FC \cdot M}$ and $r_{MC \cdot F}$, partial correlation coefficients between parent and child, given other parent; α_F and α_M, coefficients of paternal and maternal effects of additive transmission (see Table 4). Significance given on same scale as given in footnote labeled *. ‡Test of goodness of fit χ^2's have 1 degree of freedom, except those marked by §; these were analyzed in terms of transmission from one parent, and the χ^2's have 2 degrees of freedom.

Disattenuation (*16*) of correlations substantially increases many of the similarities (Table 3) and the order of importance is changed to the following: (i) parent-offspring, religion/politics > beliefs > entertainment > sports/habits; (ii) father-mother, beliefs > religion/politics/entertainment > sports/habits; and (iii) friend-friend, belief > politics > sports > religion/entertainment/habits. The major change is for beliefs (including superstitions), which thus show more similarity between parents and children than raw correlations would indicate. However, the standard errors of disattenuated coefficients (not shown) are much higher than those of the raw ones. We will not use disattenuation in the analysis that follows, but it is clear that results showing substantial effect of disattenuation might be considerably strengthened if studied by other designs with smaller observational error.

Analysis of Cultural Transmission

Our theory of cultural transmission (*2, 7*) can be used to relate familial correlations to transmission parameters. Correlations, however, are symmetric and do not indicate the direction or mode of transmission. Only a specially designed longitudinal survey which included all protagonists in the transmission process could define in more detail transmitters, receivers, and their actions and interaction.

Our survey had less ambitious goals and did not include longitudinal analysis (*17*). Our study is only a first step in relating our theory to real data and, in particular, in distinguishing relative contributions of the various modes of transmission: vertical, horizontal, and oblique. As mentioned above, such distinctions are important for understanding rates of change of trait frequencies over time as well as the variation to be expected between and within populations.

Consider first vertical transmission. Our data are based on triads—father, mother, and one child. The following is a simple model of a trait which exists in only two states, H and h, the first of which is the result of specific irreversible learning and the second is the naïve condition. To describe vertical transmission we define p_i, the relative frequency of each of four possible types of parental pairs, h × h, h × H, H × h, H × H, and b_i, the transmission coefficient or probability (assumed for simplicity to be equal for the two sexes) that a mature offspring H is produced from the respective parental pairs (Table 4). In the offspring generation the proportion of H is $u' = \Sigma p_i b_i$ (i from 0 to 3) which may be different from $u = p_3 + (p_1 + p_2)/2$, the frequency in the parental generation. If b_i is constant over generations, the trajectories of the frequency u_t of H over time can be given once the pairing rule p_i is specified. If parental pairs are random, $p_0 = (1 - u)^2$, $p_1 = p_2 = u(1 - u)$, and $p_3 = u^2$, or if the deviation from randomness can be expressed by the simple correlation between parents, $r_{FM} = (p_0 p_3 - p_1 p_2)/u(1 - u)$, and this as well as the b_i's is assumed to be constant over time, then prediction of the evolutionary result is especially easy (*2*). Certain sets of transmission coefficients have special qualitative interest. For instance, a simple interpretation of independence of the contributions from mother and father (Table 4) is the additive model, and it fits the example of Democratic party affiliation reasonably well. Since this additive model fits the data well, there is no evidence of interaction between contributions from mother (α_M) and father (α_F) to vertical transmission.

The superposition of other modes of transmission on vertical can affect the dynamics of the trait in the population. For example, suppose that after vertical transmission and before maturity the frequency of H in the progeny is u^c_{t+1}, and that later there is oblique transmission from H in the parental generation to h progeny, which converts the latter at the rate f to H. Then the progeny frequency of H at maturity is $u_{t+1} = u^c_{t+1} + fu_t(1 - u^c_{t+1})$, where u_{t+1} is analogous to u' used earlier. If, instead of oblique transmission, there is horizontal transmission from H in the progeny to h in the progeny, then $u_{t+1} = u^c_{t+1} + fu^c_{t+1}(1 - u^c_{t+1})$. If $\beta_0 > 0$ (Table 4), transmission to the offspring may have occurred from nonparental sources, possibly as a result of horizontal and oblique transmission, and there might also have been innovation by the offspring (*2*). In this way β_0 represents a maximum to the possible contributions of oblique and horizontal transmission and can be compared with $\alpha_F + \alpha_M$, a measure of the importance of vertical transmission. In the example (Table 4), vertical transmission appears to be more important than oblique and horizontal together, since $\beta_0 = .27$ is less than $\alpha_F + \alpha_M = .65$. In order to assess the relative role of vertical transmission we evaluate an index $1 - \beta_0/u'$, termed an index of vertical transmission (*IVT*), and note that, under an additive model, it is 0 when vertical transmission is absent and 1 when vertical transmission is complete. At evolutionary equilibrium $IVT = \alpha_F + \alpha_M$ un-

Table 6. Analysis of goodness of fit of additive and log-linear models (based on tests in Table 5) for the 41 traits. The probabilities corresponding to each χ^2 are tested for agreement with the rectangular distribution expected for a perfect fit. The observed numbers of traits were entered in the corresponding classes of χ^2 probabilities for the additive and the log-linear model as were the expected numbers of traits for a perfect fit of the two models. Comparison of expected and observed numbers of traits shows excellent agreement both for the additive and the log-linear models; χ^2 with 5 degrees of freedom is 2.46 and 5.72 for additive and log-linear models, respectively.

Probability of χ^2	Number of traits		
	Observed (additive)	Observed (log-linear)	Expected
.9 to 1.0	2	1	4.1
.7 to .9	8	9	8.2
.5 to .7	7	12	8.2
.3 to .5	11	6	8.2
.1 to .3	9	9	8.2
0 to .1	4	4	4.1

der the additive model (2). A limitation of the data in regard to interpretation of β_0 is that parents and offspring are evaluated at different ages. The ideal assessment of the two generations at similar ages presents obvious practical difficulties. Other potential sources of oblique and horizontal transmission will be considered later.

Summary analyses of all traits (Table 5) include the maximum likelihood estimates and their standard errors for the transmission parameters of the additive model, which fits the data satisfactorily (Table 6). For comparison, the goodness of fit of another well-known model, the log linear (18), was also tested. The χ^2's of the three-factor interactions for the log-linear model (Table 5) for all traits and their distribution (Table 6) show that the additive and the log-linear models give similar results. An advantage of our additive model is the natural interpretation of the estimated parameters β_0, α_F, α_M. A disadvantage is that it is more restrictive than the log-linear or logistic models, for example, in that the additive model may produce no fit because of the generation of negative expected frequencies. This occurred for four traits (Table 5). Two other models were fitted for these traits: (i) paternal transmission only and (ii) maternal transmission only. In the four cases of no fit with the additive model, the χ^2 values and the estimates α_F and α_M (Table 5) are those obtained from the model that gave the better fit by χ^2. In three cases the model was of maternal transmission only ($\alpha_F = 0$) and in the other, paternal transmission ($\alpha_M = 0$). We have explored only a tiny fraction of the models that might be applied to these transmission situations; others have been described (2, 7).

It is interesting to relate these statistics to the commonly employed measurements of correlation (Table 2). In general, the estimated values for α_F and α_M are similar to but slightly greater on average than the conventional partial correlation coefficients between father and child given mother, and mother and child given father, respectively (Table 5, $r_{FC.M}$ and $r_{MC.F}$). Raw correlations (Table 5, r_{FC} and r_{MC}) are clearly inadequate assessments of vertical transmission. In particular, the *IVT* values (Table 5) show that vertical transmission is often substantial. If the *IVT* were equal to 1, the trait would be maintained in equilibrium at its present frequency without other modes of transmission and without contribution from other sources increasing the frequency of the trait (that is, for $\beta_0 = 0$).

Religious and political attitudes and affiliations have the strongest vertical transmission. After disattenuation, most lower *IVT* values would increase considerably, but the interpretation of disattenuated coefficients is not unambiguous and statistical significance is often lost. Averages ($\pm$ standard deviations) of *IVT*'s in the six categories are: religion, .77 $\pm$ .09; politics, .61 $\pm$ .11; entertainment, .19 $\pm$ .05; beliefs, .17 $\pm$ .04; sports, .12 $\pm$ .05; and habits, .09 $\pm$ .05.

In terms of the relevance of our theory, the values of *IVT* (Table 5) are expected to equal the sum of the estimates α_M and α_F if our sample represents an equilibrium population, that is, if the trait frequencies in parents and children are identical, with the additive model $IVT = \alpha_F + \alpha_M$. Indeed the degree to which this identity fails may measure the departure from equilibrium. Thus in the example of Democratic party affiliation, $IVT = .49$ (Table 5) and $\alpha_F + \alpha_M = .65$. In this example the trait frequencies in parents and children are $u = .39$ and $u' = .53$, respectively, a statistically significant difference. We cannot distinguish from our data whether such differences (of which this may be an extreme example) are age-related or reflect waves of cultural change. Most other traits (Table 5) seem, in terms either of *IVT* or the direct comparison of u' and u, to be close to equilibrium.

The sharp differences noted between the strong vertical transmission observed for religion and politics, and that for the other classes of traits, demand an explanation. We cannot exclude errors of observation, as discussed above, but it is possible that the traits other than religion and politics are less stable during individual development. The result would be lower correlations between pairs of individuals, as with error of measurement. Moreover, it is natural to expect that traits which exhibit the lower correlations have less well defined, and perhaps later, critical periods during which individuals are particularly susceptible to external, rather than to parental, influences.

A finer analysis of the nature of the observed vertical transmission requires us to address three additional possibilities. First, the observed intergenerational transmission might be the result of components of oblique rather than truly vertical transmission, and these components might not be included in β_0 because they are confounded with socioeconomic stratification of parental pairs.

To investigate this possibility we looked at the data on parental income and occupations. These showed only modest correlations with the traits under investigation, and partial correlations of parent with child (given the other parent) were hardly affected when we partialed out income and professions of father and mother. At least this particular facet of oblique transmission seemed to be unimportant in our sample.

Second, if the transmission is truly vertical, does it have a genetic component? It should be stressed that our results (Table 5) do not allow a clear distinction to be made between vertical transmission that is genetic, cultural, or some mixture of these (19). It is well known that the most powerful assessment technique uses adoption (20), data for which were not available to us. However, Loehlin and Nichols (21), in their study of twin candidates for the National Merit Scholarships, asked a number of questions sufficiently similar to ours that direct comparison seems appropriate. They found that although the correlations between twins were often high, the differences between correlations of identical and fraternal twins for the two categories of traits that showed the highest vertical transmission in our data, namely, religion and politics, were generally small. This finding suggests that the transmission of these traits may have little or no genetic basis. For some traits other than religion and politics the correlations of identical and fraternal twins showed small but not negligible differences, so that possible contributions of biological inheritance to vertical transmission cannot be excluded.

Third, what is the effect of horizontal transmission? Some of this might not be included in β_0 but be confounded with the vertical component; for instance, there may be influence from older siblings, to the extent that the latter were affected by parents (*22*). We have no estimates for such intrafamilial transmission from the present survey. However, we were able to obtain additional information on horizontal transmission.

Assortative Mating and Horizontal Transmission

Since most parental pairs in our study had been together for at least 20 years, it is impossible from our data to distinguish true assortment at the time of marriage from later convergence. Convergence would involve horizontal transmission between spouses, and its separation from assortment at marriage would require a great deal of longitudinal information (*17*, *23*). Without attempting this breakdown, we can use some of our data (Table 5) to demonstrate the present correlations between marriage partners, with the Democratic party affiliation as an example (Table 7).

Table 7. Contingency table of Democratic party affiliation of parental pairs from Table 4.

Trait	Father Democrat	Father not Democrat	Total
Mother Democrat	5	27	82
Mother not Democrat	14	99	113
Total	69	126	195

The association is tested by χ^2 (in this example $\chi^2 = 64.84$, $P < .001$), and the association can be measured by $r_{FM} = \chi/\sqrt{N}$ ($r = .58$), where N is the total number of parental pairs and the sign indicates the difference between the products of the diagonal elements [(55 × 99) − (27 × 14)], positive in this case (*24*). Father-mother correlations computed in this way (column 1 in Table 8) are almost all significantly greater than zero. The order is similar to that both for vertical unattenuated transmission and for agreement, namely: religion/politics > entertainment/sports > beliefs > habits, with beliefs and entertainment interchanged after disattenuation. Marital correlations are on the average the highest (Table 2). This explains the better correspondence between our α's (Table 5) and the partial, rather than the raw, correlation coefficients.

The data on friends supply potential information on horizontal transmission. There were only a few statistically significant differences in patterns of correlation between sexes, either when comparing correlations of students with a friend of the same sex or a friend of the opposite sex, or those of male students with female students (Table 8). With these results pooled, the order of uncorrected similarities (before attenuation) is: religion > sports/entertainment > politics/beliefs > habits. After attenuation, the order changed substantially: beliefs > politics > sports/entertainment > religion > habits. As noted, all transmission correlations tend to be lower among friends than they are among parents. The longer time available for horizontal transmission and the requirements for partner selection, which are likely to be more stringent for the choice of a mate than for the choice of a friend, might

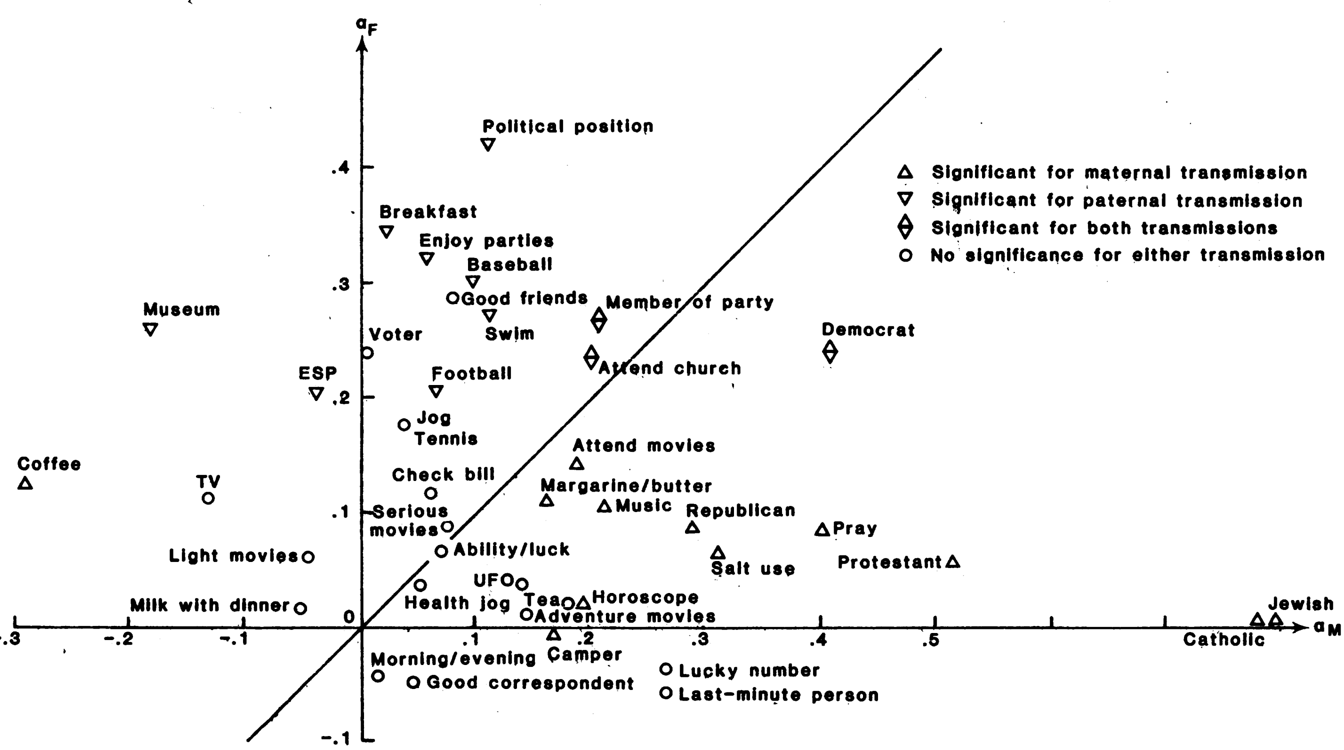

Fig. 2. Coefficients of paternal and maternal transmission (α_M and α_F) estimated for 41 traits on the basis of data shown in Table 5 from an additive model of vertical transmission. The 45° line corresponds to equal influence of father and mother; α_M and α_F are statistically significant if their departure from zero is greater than twice their estimated standard errors. The standard errors are obtained from the maximum likelihood estimation, and the test of significance is approximate, especially if the number of informative (H × h and h × H) parental pairs is small.

contribute to the almost threefold difference in average correlations (Table 2). The lower agreement ($r = .33$ for friends and $r = .45$ for parents) partially explains the lower correlations between friends than between parents. Even so it is likely for many of these traits that vertical transmission is stronger than horizontal.

Discussion

Our quantitative theory of cultural evolution suggests that information on the rules of cultural transmission is critical to prediction of variation between and within populations over time and space. We have suggested ways to use survey data for the operation and measurement of some components of transmission. The analysis here has been centered on dichotomous traits but can in principle be extended to polychotomous and continuous traits (2).

The models have their roots in our evolutionary theory, but also seem to be in excellent agreement with certain more conventional modes of analysis which may not specify a transmission model: partial correlations and log-linear analysis of contingency tables.

That our transmission models are adequate to explain the data does not preclude several other potentially important possibilities. In the parent-offspring case, for example, transmission may occur in both directions, as with many infectious diseases. The strong mother-father correlations may likewise have a component of reciprocal horizontal transmission. No statistical measure of association can indicate bona fide causation (in our study, transmission). Yet if an individual, at the end of a period of socialization and education, resembles its mentors, some process of transmission (conscious or subconscious) must have been going on.

We find strong vertical cultural transmission for political tendencies and religion. This is not unexpected. Significant vertical transmission is also present for a number of other traits represented in our categories of entertainment and sports, superstitions and beliefs, and customs and habits. In some cases mothers are important transmitters, and in others fathers appear to do the transmitting (Fig. 2), but for all traits the data are compatible with zero interaction between the two parental components. We have pointed out the important distinction between vertical cultural and vertical biological transmission. It is interesting that the traits in our study that exhibit the strongest evidence of vertical transmission cannot have an important biological component.

It is likely that the ages of the subjects in surveys such as ours will affect the results. It is likely also that the various forms of contact change with age, as does sensitivity to the reception of cultural transmission (25). Both are likely to be trait-specific, and individual differences may exist. These considerations together with the fact that the mode of cultural transmission is presumably also culturally transmitted suggest that variation between and within populations could be strongly influenced by age-related variables.

We realize that our sample is small and, like most survey samples, biased. It may be possible to apply methods of analysis such as we have described to larger data sets, from various cultures, and to longitudinal data as well as single time points. It will be important to study the relative influence of many mechanisms of cultural transmission. Longitudinal observations will be invaluable in assessing the constancy and direction of influence, possible age effects, and critical periods. Even in their absence, our transmission models augment correlational analysis and in so doing provide a better perspective from which to evaluate transgenerational comparisons and to make predictions about cultural evolution.

Table 8. Horizontal transmission and assortment of traits. Correlations are between a students' father and mother (r_{FM}), between a male student and a male friend (r_{BB}), between a female student and a female friend (r_{GG}), between a female student and a male friend (r_{BG}), and between a male student and a female friend (r_{GB}). Self-ratings were used throughout. Significance of r is coded as follows: 1, $P < .05$; 2, $P < .01$; and 3, $P < .001$. The significance of heterogeneity refers to the correlations between friends (r_{BD}, r_{GG}, r_{BG}, and r_{GB}), and P is coded as before.

Trait	Correlations and significance										Heterogeneity (P)
	r_{FM}	P	r_{BB}	P	r_{GG}	P	r_{BG}	P	r_{GB}	P	
R 1	.62	3	.38	1	.46	3	.11		.36	2	
R 2	.39	3	.19		.30	1	.11		.39	2	
R 3	.82	3	.28		−.06		.18		.27	1	
R 4	.93	3	.45	1	.20		.42	1	.20		
R 5	.66	3	.11		.14		.19		−.12		
P 1	.34	3	−.10		.22		−.14		.05		
P 2	.41	3	.18		.25		−.02		.03		
P 3	.62	3	.07		.01		.37	1	.07		
P 4	.57	3	−.03		.02		.10		.08		
P 5	.39	3	.32	1	.14		.18		.04		
S 1	.32	3	.25		.25		−.03		.17		
S 2	.55	3	.00		.00		.29		.35	1	
S 3	.14	1	.03		.25		−.14		.24		
E 1	.32	3	.34	1	.22		.28		.17		
E 2	.46	3	.12		.08		.27		.17		
E 3	.19	2	.43	2	.33	1	.18		.28	1	
E 4	.31	2	.41	1	.32	1	.32	1	.12		
E 5	.39	3	.00		−.01		.00		.38	1	
E 6	.36	3	−.14		−.19		−.14		−.04		
E 7	.14	1	.03		.12		.03		.07		
E 8	.50	3	.25		.15		.18		.43	2	
E 9	.13		.10		−.09		−.09		.28	1	
E 10	.18	1	−.38	1	.05		−.23		.05		
E 11	.16	1	−.09		.17		.05		−.04		
H 1	.12		.00		.19		.05		.10		
H 2	.18		.04		.19		.14		.23		
H 3	−.07		.45		−.14		−.36		−.23		3
H 4	.12		.65	2	−.02		.06		.07		3
H 5	.06		−.05		.01		.45		.01		1
H 6	.44	3	.11		.06		.02		.11		
H 7	.01		−.49		−.04		.33		.06		2
H 8	.27	2	−.39		−.05		.30		−.26		2
H 9	.55	3	−.10		−.15		−.22		−.05		
H 10	.11		.00		.11		.13		.02		
B 1	.12		.15		.18		.24		.17		
B 2	.28	3	.16		.10		−.02		−.06		
B 3	.32	3	−.02		.05		−.02		−.24		
B 4	.19	2	.01		−.08		−.12		.00		
B 5	.09		−.04		.04		.30		.09		
B 6	.21	2	.03		.34	1	.02		.24		
B 7	.34	3	−.27		−.21		.07		.09		

Other potential applications of this approach to the study of cultural transmission may be found in linguistics, psychology, anthropology, sociology, and communication sciences. Perhaps the most exciting prospect is that of being able to use observations on transmission to predict variation between individuals and populations, over space and time.

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12. Those questions whose answers were positions on a scale were dichotomized at the mean. This conservative approach made the analysis reasonably distribution free and allowed comparisons with the model of Table 4. It is also practically insensitive to inadequacy of scales, a major problem with graded data, although there is a cost in lost information. If graded scales were used, analysis by linear structural equations could have been employed [L. L. Cavalli-Sforza and M. W. Feldman, *Genetics* **90**, 391 (1978); C. R. Cloninger *et al.*, *Am. J. Hum. Genet.* **31**, 366 (1979); S. Karlin, *Theor. Pop. Biol.* **15**, 308 (1979)]. Some of the pitfalls of this approach have recently been stressed by A. S. Goldberger [in *Genetic Epidemiology*, N. W. Morton and C. S. Chung, Eds. (Academic Press, New York, 1978), pp. 195–222], by M. W. Feldman and L. L. Cavalli-Sforza [in *Genetic Analysis of Common Diseases: Applications to Predictive Factors in Coronary Disease*, C. F. Sing and M. Skolnick, Eds. (Liss, New York, 1979), pp. 203–227], and by S. Karlin [in *ibid.*, pp. 497–520].
13. Father and mother were those regarded by the student as having that role. The first time the questionnaire was used it was sent to the parents and friends of the student, producing five evaluations of the student. Because of the low return from friends the first year, when the questionnaire was given to students in the same classes 1 year later one randomly chosen set obtained parental evaluations and another set obtained those of friends. Each set produced three assessments of the student. The parents and friends collections were each pooled over the 2 years. In the second year, 11 more questions on customs and habits were added, and assessments are therefore based on smaller totals. Minor differences between total numbers for the various traits reflect blank entries.
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15. The slash (for example, in sports/politics and other cases) indicates that the categories are close in the ordering.
16. One method of removing the effect of attenuation is to compute the ratio similarity: agreement. Thus, suppose that the observed value in one individual is ϵ and in a second is η and that each is the sum of two independent random variables $\epsilon = x + \epsilon_1$, $\eta = y + \epsilon_2$ where ϵ_1 and ϵ_2 are independent errors having variances σ_1^2 and σ_2^2, and x and y, with variances σ_x^2 and σ_y^2, are realizations of a "true" value for the trait. Then the observed correlation $r_{\epsilon\eta}$ is equal to $r_{xy}r$, where $r = \sigma_x\sigma_y/[(\sigma_x^2 + \sigma_1^2)(\sigma_y^2 + \sigma_2^2)]^{1/2}$ averages the intraclass correlation or fraction of variance due to x and y. We use the agreement between observers as an estimate of *r*, so that the division of the observed correlation by the agreement can be regarded as an estimate of the true correlation. If self-ratings were actually accurate, however, this procedure would result in an overestimate. On the other hand, raw correlations from self-ratings only were not higher on the average than those based on ratings by others. This contrasts with the expectation if self-ratings were substantially more accurate.
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