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The Minnesota Twin Family Registry: Some Initial Findings

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Abstract. A birth-record based Registry is nearing completion of some 8,000 pairs of twins born in Minnesota from 1936 to 1955, plus some 1,200 pairs of male twins born 1971-81. The middle-aged twins were recruited with graded incentives so that ease of recruitment could be measured; it was found that pairs concordant for ease of recruitment were no more similar than discordant pairs in education, socioeconomic status (SES), or a variety of personality and interest factors, ie, that selection bias may not be a problem in research with adult twins when contacts are only by mail. A 50% decrease in neonatal mortality from 1936-55 to 1971-81 was associated with an increase from 3.5 to 4.0 per thousand in the frequency of viable MZ twin births. The broad heritability of SES, educational attainment, fecundity, and risk for divorce ranges from 0.30 to 0.50, although all 4 variables are plainly multifactorial and the latter 2 both involve variance contributed by a second person. Investigators interested in making use of this research resource are invited to submit proposals.

Key words: Twins, Registries, Recruitment bias, Birth rate, Birthweight, Perinatal mortality, Divorce risk, Fecundity

Beginning in 1983, we have been constructing what we believe will be the largest birth-record-based twin registry in the United States. When completed in 1990, the Registry will comprise about 80% of the approximately 10,400 surviving intact pairs born in Minnesota from 1936 through 1955, about 8,400 pairs in all (see Fig. 1). In a separate project, we have located and added to the Registry about 91% (1,200 pairs) of the male pairs born from 1971 through 1981. We also have obtained the computerized birth records of all multiple births in Minnesota from 1959 through

1987 and hope to locate and add many of these families to the Registry in the future.

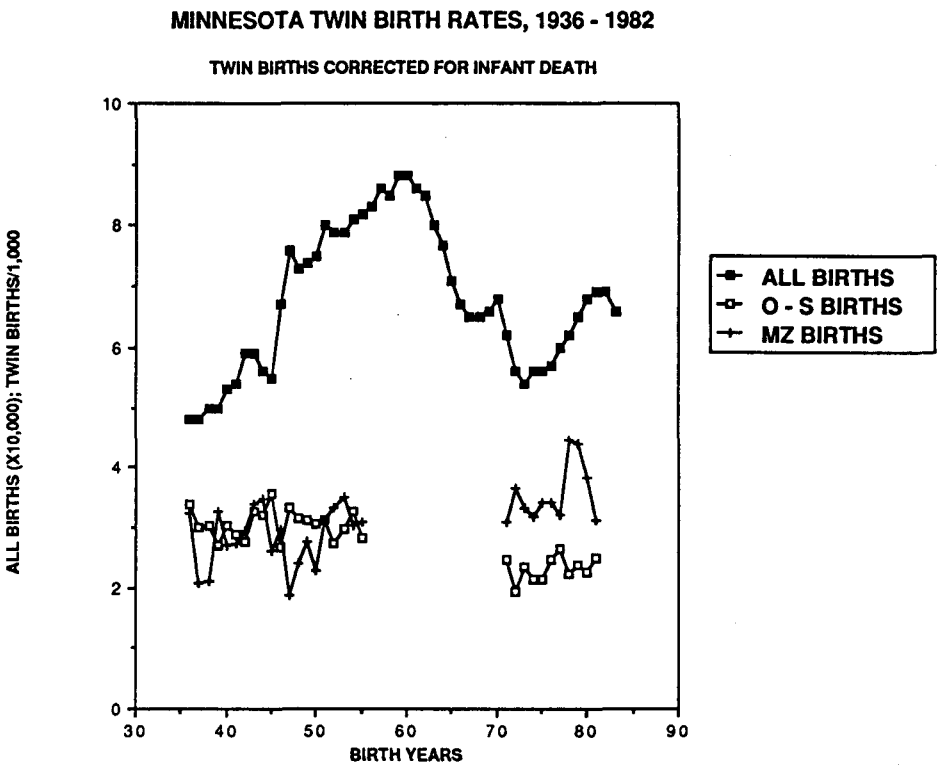

Fig. 1. All Minnesota births (x 10,000) plotted together with birth rates (x 1,000) of opposite-sex (O-S) and monozygotic (MZ) twin pairs for the older and younger cohorts of the Minnesota Twin Registry. MZ rates estimated by Weinberg's formula. Assuming O-S rates are typical of dizygotic (DZ) twins generally, the DZ birth rate has decreased considerably while the MZ rate has increased slightly.

The value of using twins in the study of both genetic and environmental influences, as well as their interaction, first pointed out by Galton [17] and elaborated by many others seems recently to be gaining wider appreciation in the scientific community [3,4,13,14,18,22,26]. It is our impression that psychological and biomedical researchers, in increasing numbers, are becoming interested in accessing twin samples and we anticipate that other investigators may wish to establish twin registries in their own areas. The purpose of this article is to describe the Minnesota Registry, to outline how it was established, and to explain how we propose to make it available to other researchers. We shall present some demographic data and examine evidence concerning the extent to which the monozygotic (MZ) and dizygotic (DZ) participants are representative of the population from which they were recruited.

ESTABLISHING THE REGISTRY

Ascertainment

Our first step was to arrange with the State Health Department, whose main offices are situated conveniently on the University campus, to allow us to xerox all birth certificates reporting multiple births (Minnesota birth records prior to 1959 have not been computerized.) Although the information contained in these birth records varies some from year to year, it typically includes the following: the child's name and sex, the name, age, race, and occupation of the father, the full maiden name, age, occupation, race, and address of the mother, the date, time, and place of birth, the number of living children born previously to this mother, whether this was a multiple birth and the order of birth of this child, the birth weight and length, and the name of the attending physician, midwife, or other informant. Pairs (sets) of records reporting one or more still-births or infant deaths, as well as records of illegitimate births, we have discarded from further consideration.

Locating the Twins

There exists a variety of methods for locating the present whereabouts of twins ascertained from birth records. Since some methods are more cost-effective than others, it is important to apply the cheaper methods first, saving the more costly ones for the obdurate cases. Our first step is to search the state's death records for 6 months following the date of birth to ascertain infant deaths. The next step depends on the twins' present age; if the parents are likely to be still living, it may be easiest to locate them, especially in the case of female twins both of whom may have changed their surnames through marriage. We find that many of the parents who still reside in Minnesota can be readily located with the help of telephone directories (or Directory Assistance), beginning in the area where the twins were born. Failing this, it may be helpful to call other persons in the area with the same surname who might be relatives; this works best when the birth was in a small community or when the father's surname was an unusual one. If the father has a common name (eg, in Minnesota, a name like Robert Hanson), but the mother's maiden name was uncommon, it may be possible to trace the family through the mother's relatives.

Next, one can employ a reverse directory (organized by location and address rather than by name of resident) to identify persons now living at the parent's former address. These individuals may know where the former tenant is now or may at least be able to provide the name of a long-resident neighbor who would have known the former resident and might now be able to provide a lead. Other possibilities include contacting the father's former employer or the birth hospital, if this information is on the birth certificate. On rare occasions, when dealing with smaller communities, we have identified the high school that the twins once attended and, with the school's help, located a classmate still living in the community and

still in touch with the twins; the classmate who took charge of the most recent class reunion is an especially promising resource.

If one is attempting to locate adult twins directly, rather than through their families, after eliminating cases of infant death we proceed to search the marriage records to identify name changes of the female twins since some 86% of those over 30 will have married. The next step, because it is so cost-effective, may be to search the state's driving license records. In Minnesota one can conduct a computer search of these records, given the full name and birth date, for just 50 cents per name.

Where the twins now reside out of state, some of these techniques are not available. However, since all one needs to locate is one family member or other informant, we have managed to contact more than 80% of twins aged 30 to 50 who were identified from birth records and more than 90% of the families of twins born from 8 to 17 years previously. (In some unknown proportion of the missing cases, at least one twin will have died so that the pair, at least for our purposes, is of no interest.) We have used undergraduate students as "twin finders", making each student responsible for identifying and locating all twins in a particular birth year. The time investment per pair located has ranged from 15 to 45 minutes from one twin finder to another and is shorter for younger twins than for middle-aged ones; the median search time is less than the mean because the distribution is positively skewed. We could undoubtedly have increased somewhat the percentage of pairs located but found that the time and cost investment increased sharply above 80% for the older cohort and above 90% for the younger twins still living at home.

RECRUITMENT

The Biographical Questionnaire

Our approach to recruitment has been to send the located subjects a 4-page Biographical Questionnaire (BQ) in the first mailing together with an introductory Newsletter, describing the project, and a copy of a letter signed by Minnesota's Governor urging participation. We find that 60% to 70% of individuals respond within 6 to 8 weeks. Non-responders are then prompted by telephone. Many of these individuals have mislaid (or never received) our first mailing and readily agree to complete and return a second BQ that we send them. Others still have the first BQ in hand and our phone call suffices to induce them to complete it. We find that 2 telephone prompts, 6 to 8 weeks apart, yield return of the BQ from a total of about 80% of the twins originally contacted.

Mass mailing, in batches of at least 200 identical packets sorted in zip-code order, costs (in the US) about 1/5 of first class rates. Sorting is automatically achieved by computer generation of mailing labels in the desired order. Duplicate mailing labels are affixed to the booklets to be returned to insure correct identification. Mailing envelopes are labeled "Forwarding and Address Correction Requested", a service which incurs an additional charge but that more than pays

for itself in tracking down participants who have moved since our last contact with them.

At the time of this first mailing, our computer data-base consists of the birth record information plus the address information obtained by our twin finders. Upon receipt of the BQ, its information is hand-entered into the data-base and provides, among other things, information about the current structure of the twin's family. We then send a packet of test materials to the twins and, if they are married, to their spouses. For the first 6 birth-year cohorts, these were bound together in a rather forbidding booklet containing 6 separate inventories totaling nearly 700 items. A 4-page, computer-coded IBM-type answer-booklet was included and respondents were required to enter their answers by blackening the appropriate circle in the answer-booklet.

Data Entry

We soon discovered that, surprisingly, the technology of optical scanners is not far advanced and that the scanned answer sheets had to be edited and often corrected by hand. Moreover, many average citizens have had little experience with such answer sheets and find it easier and quicker to simply circle the chosen answer right in the test booklet. Our present practice, therefore, is to bind each inventory separately, labeled with the respondent's name and identification number (ID), to print them so that answers can be marked directly beside the test question, and then to hand-enter the results when the booklets are returned. One can devise computer entry programs that create on the monitor a display of each test page as the answers are entered, and that test on-line for answers that are out-of-range. The data are entered again later by a different clerk using a program that flags discrepancies on-line so that the second clerk can check that entry for accuracy.

Zygosity Determination

The Biographical Questionnaire included the 5 questions listed in Table 1, very similar to those employed by prior authors [9,10,35] in achieving an accuracy of some 95% in zygosity diagnosis. Since 74 pairs of Registry twins had participated in an earlier laboratory study, for which their zygosity was established by elaborate serological analysis [25], it was possible to validate our questionnaire method for these 148 individuals. When pairs with mean zygosity scores of 4 or higher are classified as monozygotic, and all others as dizygotic, 1 of 49 pairs of MZ twins and 2 of 25 pairs of DZ twins were misclassified, yielding an overall validity of 96%. Zygosity was determined in this manner for the 1,309 pairs, from the first 6 birth-year cohorts, of which at least one member returned a BQ. Of this total, 47% were male pairs and 48% were MZ pairs. Of the 791 pairs of which both twins returned the test data, 35% were males and 54% were MZ pairs. Test data was returned by 73% of individual female twins but by only 47% of the males.

Table 1 - Questions used for zygosity diagnosis[a]

A. Your eye color:
Same color (1) Similar, different shade (0) Different color (−5)

B. Your (natural) hair color:
Same color (1) Similar, different shade (0) Different color (−5)

C. (Even identical twins sometimes differ quite a bit in height or weight as a result of accident or illness. In answering the questions below, try to ignore such differences.)

1. During your childhood, were you and your twin as alike as "two peas" or were you no more alike in appearance than ordinary brothers or sisters?
   Like "two peas" (3) Ordinary likeness (0) Quite unlike (−3)
2. When you were school age, were you similar enough in appearance so that people had difficulty telling you apart?
   Never (−2) Sometimes (2) Even family had difficulty (3)
3. Could you ever have fooled friends or family by pretending to be your twin?
   Yes (2) Maybe (0) No (−1)

[a] Weights assigned to each alternative answer are shown in parentheses. These weights were assigned rationally (eg, different eye or hair color ensures dizygosity; general physical similarity gets more weight than similarity on one trait) and the cutting score chosen from inspection of the bimodal distribution for the total same-sex sample. Twins are classified as monozygotic if the sum of the weighted responses is +4 or higher.

The Lottery

On the second (and final) telephone prompting of persons who had not returned the BQ, they were told that participation of both twins would cause their names to be entered in a lottery with a prize of $1,000 and that there would be a separate lottery for each birth year so that participating pairs would have nearly one chance in 200 of winning. To pay each twin in 1600 pairs even $10, probably a threshold inducement, would have cost $32,000 as compared to $6,000 for the lottery. By entering all participants' names in the lotteries but revealing this inducement only to the most reluctant, as a last-chance recruitment effort for those few, we managed to increase the number of tested individuals by about 17% and the number of concordant pairs by 30% (see Table 2) while at the same time giving the more cooperative pairs an equal opportunity to win the prizes.

It is important to note that the lottery was used as an incentive only with the minority of reluctant twins who had already indicated that they would not participate without some added compensation. Therefore, our participants are not selected for cupidity nor as persons who are especially attracted by games of chance. That is, our sample includes all those subjects who would normally participate in such studies, either out of interest or a desire to contribute to research, plus an additional group who would not otherwise have been sampled, and it is thus rather more representative of the general population than it would have been without the lottery.

Table 2 - Recruitment success for the same-sex twins of the first 6 birth-year cohorts[a]

		Individuals		Concordant pairs	
		N	%	N	%
Biographical questionnaires sent		3,258		1,629	
BQ returned:	No prompt	2,385	73	1,027	63
	One prompt	2,573	79	1.136	70
	Lottery prompt	2,601	80	1,163	71
Test booklets sent		2,585		1,155	
Tests returned:	No prompt	1,160	45	354	31
	One prompt	1,619	63	598	52
	Lottery prompt	1,909	74	791	68

[a] Telephone prompting increases return rates substantially. Offering a chance to win $1,000 in a lottery on the second prompt does not influence many of those who did not even return the BQ but it increases substantially the willingness of (especially male) twins to spend several hours filling out questionnaires.

Although this lottery inducement worked tolerably well, we have subsequently reverted to direct payment to reluctant subjects. This has the disadvantage that the more cooperative individuals, who comprise the vast majority, receive no monetary compensation. However, direct payment of $10 seems to attract as large a proportion of the reluctant individuals as does the lottery incentive and lotteries, it turns out, are illegal in many jurisdictions. We rationalize the fairness issue by pointing out that we are dealing in a seller's market; the majority, who participate for nonmonetary incentives, are apparently adequately compensated while the reluctant minority would not feel adequately compensated without the cash payment. The objective, after all, is to approximate as nearly as possible a final sample that is truly representative of the population of all twins originally identified.

Biographical Data

Our purpose in establishing the Registry was two-fold. First, we wished to have ready access to large, relatively unselected samples of twins and their families as a research resource for ourselves and for other investigators. The Minnesota Study of Twins Reared Apart [3,4] has generated many hypotheses that require testing on large, representative samples of middle-aged twins. Secondly, we wished to make first use of this resource by collecting such data from the located twins as was possible and useful by mail. This second purpose fed into the first in several ways. The biographical data make it possible (a) to establish twin zygosity with high confidence, (b) to determine their educational level, occupation and, from these, their socioeconomic status, and (c) to determine the make-up of their immediate families.

We also learn the following: the twins' marital status, their self-reported height and weight, how often they speak face-to-face or by telephone, the educational level and occupation of their parents and, if the parents are deceased, the cause of death, the sex and birth dates of their offspring and siblings. From a check list in the BQ, we learn which twins have suffered a disabling injury, who has been treated for alcoholism, allergy, arthritis, depression, diabetes, epilepsy, multiple sclerosis, chronic pain, hypertension, thyroid disorders, or schizophrenia, or "Any other chronic or recurring illness? Please explain". We know which twins smoke and whether they are right- or left-handed or consider themselves ambidextrous. Such information may be useful to investigators seeking twin subjects for particular purposes.

In the case of the younger cohort of male twins, a somewhat different Biographical Questionnaire, filled out by the parents, asks whether either twin, father, mother, or a male sibling has been treated for each of 28 disorders such as alcoholism, arthritis, attention deficit disorder, chemical dependency, depression, diabetes, epilepsy, learning disability, mental illness, multiple sclerosis, or speech problems. Returns from the first 900 families yield prevalences close to those expected in this population, eg, 0.9% of the mothers and 10.9% of the fathers have been treated for alcoholism, while 10.8% of the mothers and 5.0% of the fathers have been treated for depression. As might have been expected, significantly more of the twins have been treated for speech and reading problems (14.8% and 9.7%) than is true for the singleton brothers (5.1% and 6.0%).

Since we have also administered, to about half the twins, inventories of personality traits [40,43], leisure-time and occupational interests [42], attitudes [44], and other self-ratings [40], it is possible to select twins who are high or low in extroversion (Positive Emotionality), neuroticism (Negative Emotionality), aggression, hypnotizability (Absorption), conservatism, (Traditionalism) and the like. Alternatively, new data collected from samples of Registry twins can be analyzed in relation to these data already in hand.

Maintaining Participants' Interest

Another way in which our preliminary data collection contributes to the usefulness of the Registry can be derived from Festinger's theory of "cognitive dissonance" which predicts that persons who have invested of their time and effort in some enterprise will be disposed to regard that enterprise as worthwhile, a good investment, rather than to have to believe that their decision to participate had been foolish or misguided. This principle predicts that, having responded to our first modest request for biographical information, twins will be more likely to also respond to a second mailing asking them to complete the personality inventory and questionnaires about their occupational and leisure-time interests.

This principle will operate, however, only if the participants are treated considerately, provided with interesting feedback and with other evidence that the research to which they have contributed has scientific value. We send each par-

ticipant a computer-generated, personalized report of his or her scores on some 60 factor-analytically derived dimensions of personality and interest, plus 10 super-factors based on the intercorrelations of the sub-scales. We also send out newsletters, irregularly, to all participants with reports on our various studies and other information of interest to twins. The increased media attention to twin research in recent years, especially to our Minnesota Study of Twins Reared Apart [3,4], has also helped to assure our participants that they are contributing to an interesting and scientifically productive effort.

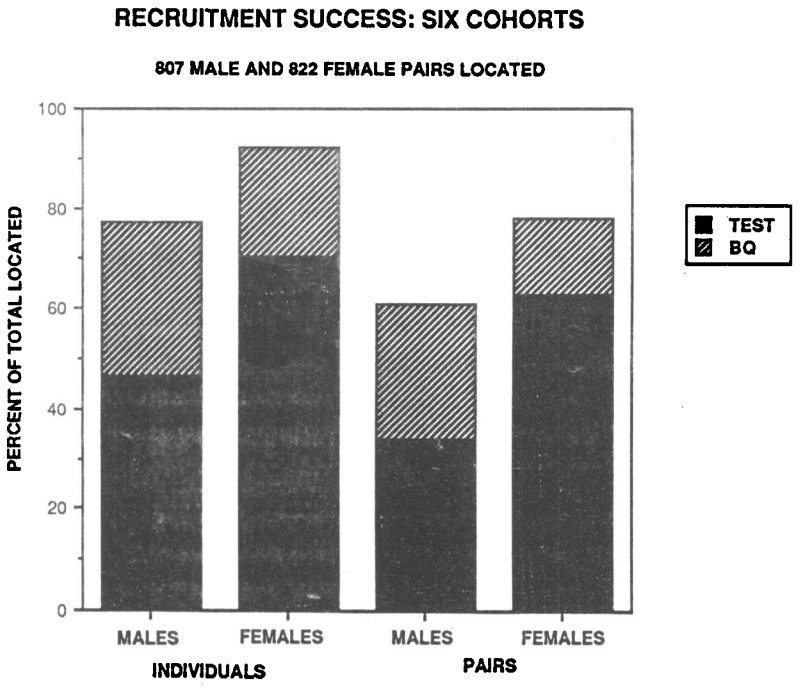

Fig. 2. Recruitment success for the first 6 cohorts, plotted by individual and by concordant pairs. 92% of the individual females returned a Biographical Questionnaire (BQ) while 63% of the female pairs were concordant for returning all tests. For males, 77% of individuals returned a BQ but only 34% of the pairs were concordant for testing.

Recruitment Success

The first 6 birth-year cohorts located were the same-sex twins born in 1936, 1937, 1938, 1949, 1954, and 1955, spanning the 20 years of the Registry. A total of 2,912 same-sex pairs were live-born in these six years, of which 779 pairs (27%) are known to have been broken by death of one or both members by the time of this study. We

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managed to locate both members of 1,673 pairs (78%) of the presumed survivors and, as shown in Table 2, BQs were sent to 3,258 individuals (in 44 pairs one twin was incapacitated or asked not to be contacted). Completed BQs were received from 2,385 (73%) of the individuals (and from both members of 63% of the pairs) within 8 weeks. One telephone prompt increased the return rate to 79% and 70%, for individuals and concordant pairs, respectively. A second telephone prompt, which offered a chance for the pair to compete in the $1,000 lottery, increased the BQ returns only to 80% and 71%. Recruitment success for individuals and for concordant pairs is graphed, separately for males and females, in Fig. 2.

The 700-item personality and interest test battery was then sent to the 2,585 individuals (including 1,155 concordant pairs) who had returned the BQ and also indicated their willingness to participate further. This set of 7 questionnaires required several hours of the subjects' time and therefore, not surprisingly, there was considerable attrition in responding, especially among male twins. Once again we employed a maximum of 2 telephone prompts of subjects who had not yet returned the completed tests. Once again, the reluctant subjects were informed, on the second prompting, that the names of all pairs in which both twins were participants would be entered in the lottery. As shown in Table 2, 45% of the individuals, and both members of 31% of the pairs, returned completed questionnaires without prompting. The first telephone prompt increased this yield to 63% and 52%, respectively, for individual twins and concordant pairs. The second or lottery prompt produced a further increase, to 74% and 68%. As is usually found in twin studies [27,29], women were much more likely to participate than men (80% vs 56%.) A similar sex ratio was found for spouses of participating twins; 78% of the wives and only 58% of the husbands agreed also to participate.

Effect of Prompting

The effect of prompting on concordant BQ and test returns is shown graphically in Fig. 3, which illustrates that being DZ, rather than MZ, has an effect on participation similar to being male, rather than female. However, the demands of the long test battery caused greater attrition among males than females, possibly because more men than women find so much reading to be onerous; 2/3 of the female pairs concordant for the BQ also were concordant for returning the tests, as compared with about half of the males. Opposite-sex (OS) pairs were most comparable to same-sex (SS) DZ males.

In Fig. 4 are plotted, for the 1,436 pairs of SS twins from the 6 completed cohorts, of which at least one twin returned a BQ, the proportions of each of the possible patterns of recruitment response. Once again we see the similar effect of sex and zygosity upon recruitment. The only exception consists of the pairs concordant for returning the BQ *and* for not completing the testing. This group contains a higher proportion of males than of females, reflecting the men's greater reluctance to be tested, but a larger proportion of MZ than DZ twins, reflecting the MZ's stronger tendency to behave concordantly.

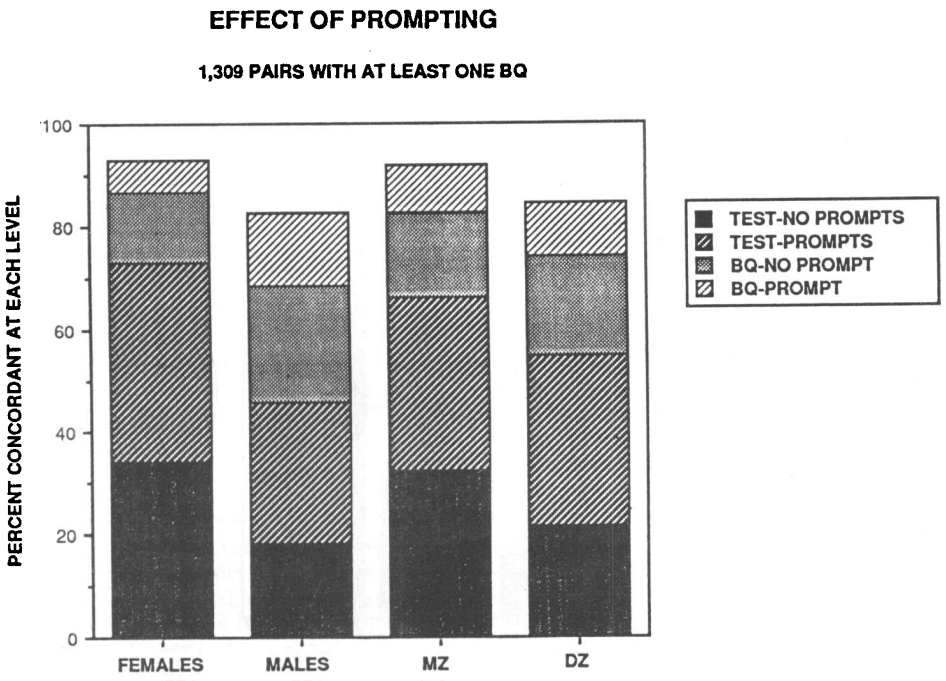

Fig. 3. Effect of prompting, first 6 cohorts. For females, 34% returned a Biographical Questionnaire (BQ) and tests without prompting, 38% returned tests after prompting, 14% returned BQs without prompting but never returned tests, etc..

The lottery incentive was also employed in recruiting parents, SS siblings, and offspring of the Registry twins (a total of 1,085 spouses of the married twins returned test data when the twins themselves did). From the twin BQs we determined which pairs had both parents living and well, which had at least 2 SS singleton siblings, and which pairs each had at least one child aged 17 or older and of the same sex as the cotwin's offspring. Special BQs and test materials were sent to these family members, followed up by the usual two telephone prompts. Complete test data were obtained from 233 parents, 169 siblings, and 285 offspring, including 42 pairs who were offspring of DZ twins and are therefore first cousins, and 44 pairs who were offspring of MZ twins and are genetic half-sibs reared separately in intact biological families. Some 69% of the spouses of the married twins, and all the spouses of twins whose offspring participated, contributed complete test data.

Our subsequent experience with the next 4 birth-year cohorts indicates that siblings and offspring can be recruited with greater success by sending the materials directly to the relative (rather than to the twins to be passed on), and by offering a cash payment of $10 at the second telephone prompt. Already, 212 parents, 146 sibs, and 243 offspring have returned test materials from these four cohorts, about

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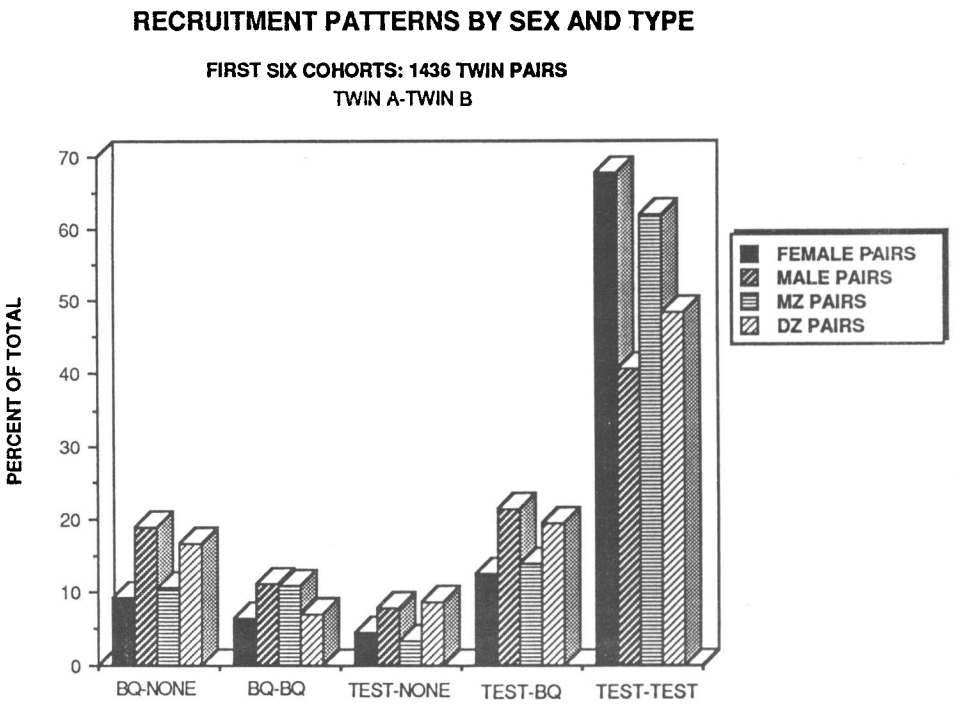

Fig. 4. All possible within-pair patterns of recruitment response for the 6 completed birth-year cohorts, excluding pairs where neither twin returned even the Biographical Questionnaire (BQ), plotted for male vs female and for MZ vs DZ pairs. Being male has a similar effect on recruitment to being DZ, except for those pairs concordant for returning only the BQ.

69% of those solicited and about 31% better than the return rate achieved in the 6 cohorts for which complete returns are in. A total of some 445 parents, 315 SS sibs, and 528 offspring have provided test data thus far and this total should double by the time the registry is complete.

DEMOGRAPHIC CHARACTERISTICS OF THE REGISTRY TWINS

Because the total of Black, Asian, and native American minorities is less than 2% in the Minnesota population, we do not identify race nor make any racial comparisons.

Rates of Twinning

As suggested in Fig 1, there was a decline in the rate of DZ twinning in Minnesota from about 7.0 pairs per thousand confinements in 1936-55 to about 5.0 pairs

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Table 3 - **Infant mortality and mortality risk**

Twin pairs lost by infant death (%)[a]

		MM	FF	OS	MZ[c]
1936-55	Mean	23.70	18.30	17.10	25.30
	SD	5.87	5.10	5.41	5.22
1971-81	Mean	11.90	8.4	7.3	12.7
	SD	2.33	3.44	2.69	2.66
$\frac{Diff}{SE_{diff}}$		8.50	7.80	7.50	9.80

Infant mortality risk[b]

	MM-MZ	MM-DZ	FF-MZ	FF-DZ
1936-55	0.149	0.099	0.112	0.076
1971-81	0.073	0.044	0.050	0.030

[a] Percent of live-born twin pairs in which one or both twins died before age 6 months. There was a highly significant decrease in twin-infant mortality from 1936-55 to 1971-81.

[b] Risk of mortality within first 6 months after birth.

[c] MZ figures estimated from MZ infant mortality risks computed separately for male and female twins, using known opposite-sex, male and female same-sex twin mortality data and assuming (1) that male risk is the same in OS and SS DZ pairs, and (2) that the ratio of male to female risk is the same in MZ as in DZ twin pairs.

per thousand in 1971-83; a similar decline has been reported for the US, Britain and northern European countries, and in Australia [1,11,12,20,23]. The rate of MZ twinning, in contrast, 3.5 in 1936-55 and 4.0 per thousand in 1971-81, has increased slightly. Doherty and Lancaster [12] report a similar increase in the MZ rate in Australia, from 3.6 in 1936-55 to 4.2 in 1971-81, while Bressers et al [5] report similar trends in several European countries. This increase in the rate of live-born MZ twins, at least in Minnesota, seems likely to have been due to improvements in prenatal and obstetrical care. As shown in Table 3, neonatal mortality is higher in male than in female twins, higher also in MZ than in DZ twins, and *decreased by more than 50% in Minnesota from 1936-55 to 1971-81*. If the MZ mortality rate had been as high in the latter period as in the former, the viable MZ birth rate would not have increased at all. Additional evidence comes from a comparison of the distributions of gestational ages, shown in Fig. 5. In 1971-81, 15.7% of the total group of surviving male pairs had gestational ages of less than 32 weeks, as compared to 1.5% in 1936-55. Had the 14.2% surplus not survived in 1971-81, the MZ rate then would have been (0.858) x 4.0 or 3.4 per thousand, close to the 1936-55 MZ birth rate. By this same reasoning, the rate of DZ conceptions has decreased even more than is indicated above; were it not for this decrease in perinatal mortality, the viable DZ birth rate would have declined from 7 to about 4.3 (instead of 5) per thousand.

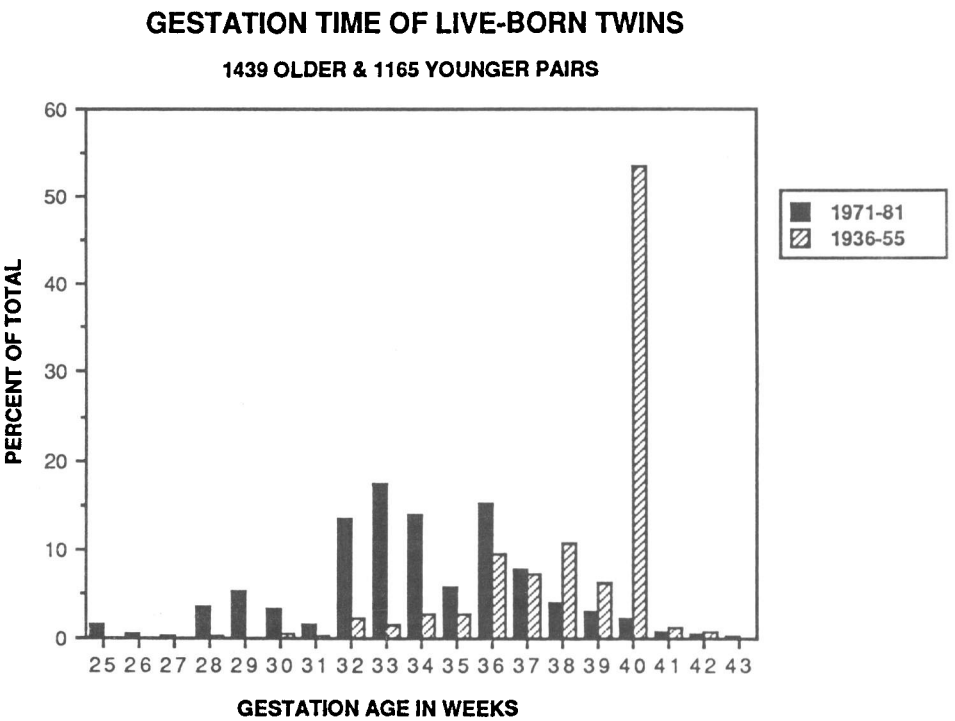

Fig. 5. Gestational age at birth as estimated from the time from the mother's last menses, for the male twins of the older cohort, born 1936-55, and the younger cohort, born 1971-81. In 1936-55, more than half of the live-born MZ and DZ pairs were carried to full term, ie, 40 weeks. In 1971-81, the mean nominal gestational age had decreased from 38.5 to 33.8 weeks, likely due to better methods of assessing fetal maturity accompanied by much greater use of cesarean delivery.

Maternal Age

The rate of DZ twinning increases with maternal age more sharply than the rate of MZ twinning [6] which suggests that mothers of DZ twins should average somewhat older than the mothers of MZs. Table 4 confirms this expectation for mothers of both male and female twins. Surprisingly, the mothers of the younger cohort of male twins were significantly younger than the mothers of the male twins born in 1936-55. Our mean maternal age for the 1971-81 mothers, 26.8 years, can be compared with the mean of 26.1 years for mothers of all twins born in Minnesota and surrounding states in 1982, as reported by Allen [1].

Table 4 - Maternal age, obtained from birth records[a]

	Female twins 1936-55		Male twins 1936-55		Male twins 1971-81	
	MZ	DZ	MZ	DZ	MZ	DZ
Mean	28.10	29.30	28.20	29.70	26.60	27.10
SD	6.42	5.90	6.36	5.64	4.90	4.59
N	1,356	1,299	1,007	1,017	513	338
MZ vs DZ						
CR[b]	5.0, P < 0.0001		5.6, P < 0.0001		1.5 (ns)	
Older vs younger males						
CR[b]	MZ = 5.4, P < 0.0001		DZ = 8.5, P < 0.0001			

[a] Only data for male twins has so far been collected for the younger cohort.
[b] CR is the ratio of the indicated difference to its standard error.

Gestational Age

Until 1981, the nominal gestational age, computed as the time from the mother's last menses, was listed on Minnesota birth records. More than half of the Minnesota twins born in 1936-55 were carried to 40 weeks, the normal term for singletons. If we define prematurity as a gestational age less than 37 weeks, following Watson and Campbell [45], then about 21% of the twins were born prematurely. It is this higher risk of prematurity, of course, that is responsible for the higher rate of perinatal injury in twins than in singletons which, in turn, increases the within-pair variance on traits susceptible to the effects of such injury, thus leading to underestimates of the heritability of such traits in single-born persons [33].

The 1,775 MZ twins in our older cohort had a mean gestational age 0.3 weeks shorter than that for the 2,265 DZs; this small difference is statistically significant and identical to the difference reported in a study of 1,855 twin pairs born in Belgium from 1964 to 1987 [41]. Our older cohort, born from 1936-55, had a mean gestational age of 38.5 weeks, longer than the Belgian mean, 37.0 weeks, which is the value reported by Bulmer [6] as the average length of a twin pregnancy, and much longer than the mean, 33.8 weeks, for our younger cohort, born 1971-81. In Fig. 5 are plotted gestational ages for the male twins of the older and younger cohorts separately. Only about 3% of the younger twins were carried to 40 weeks, compared to 57% of the older group; 82% of the younger cohort, versus 20% of the older, were more than 4 weeks "premature." This marked change, over 20 years, in the distribution of gestational ages suggests both an increased ability to sustain life in very premature infants with gestational ages less than 32 weeks, and also a great increase in the proportion of twins for whom birth is induced early or who

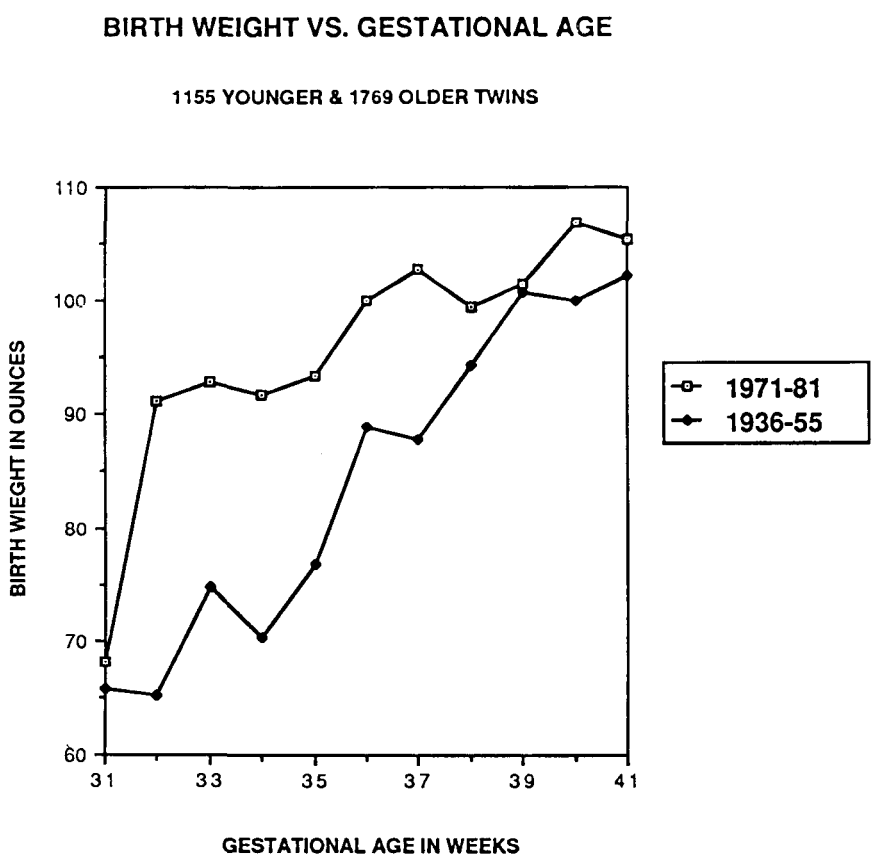

Fig. 6. Birth weight as a function of nominal gestational age for male twins born 1936-55 and for male twins born 1971-81. The latter curve suggests that better-developed infants were being taken by cesarean section at earlier nominal gestational ages.

are delivered by cesarean section (CS) at nominal gestational ages from 32 to 40 weeks.

Birth Weights

The distributions of birth weights of the Registry twins were compared by sex and by twin type. Contrary to the recent Belgian findings [41], male twins were slightly heavier than females (94.5 vs 89.3 oz, $P < 0.0001$) and DZs were significantly heavier ($P < 0.0001$) than MZ twins. Birth weight increases, of course, with gestational age, as is shown in Fig. 6. The linear increase for the older cohort can be compared with Bulmer's Fig. 3.1 [6, p.49]; the two curves are quite similar. The birth weights of the 1936-55 DZ twins average 6.3 oz heavier ($P < 0.001$) than in the Belgian study,

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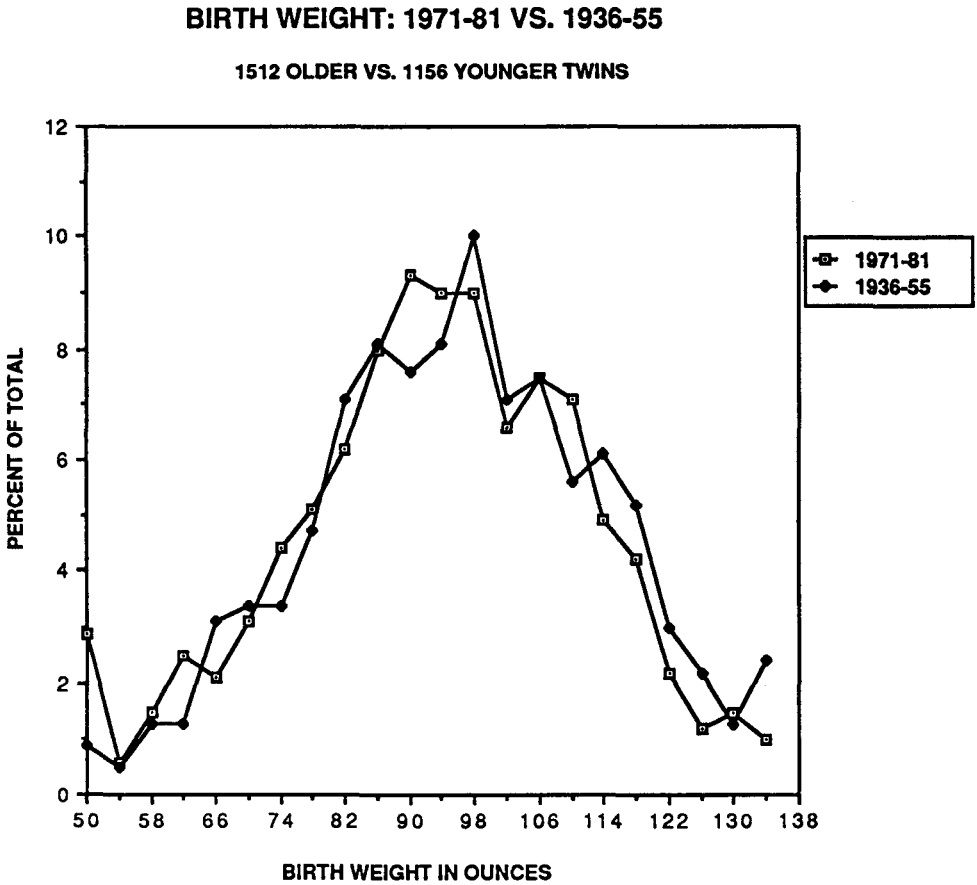

Fig. 7. *Distributions of birth weights for the male twins born in 1936-55 and in 1971-81. The similarity in the curves, except at the extremes, supports the view that the younger cohort, although their nominal gestational age averaged nearly 5 weeks less than for the older cohort, were selectively delivered on the basis of fetal maturity. (Only male twin data are available on the younger cohort.)*

about the difference to be expected given the 1.5 week longer mean gestational age.

The birth weights for the male twins born in 1971-81, also shown in Fig. 6, increase sharply between 31 and 32 weeks of gestational age. This supports the conjecture that, after a nominal gestational age of 32 weeks, many of these younger twins were taken by CS, but only after determining that they were sufficiently well developed. It should be remembered that "gestational age" as recorded on the birth record is inexact and that modern sonography provides a more accurate index of true fetal maturity. Thus, although the younger cohort were being delivered at nominal gestational ages that seem alarmingly short (Fig. 5), their actual maturation at delivery was as far along as for the older cohort. The distributions of birth weights for the older and younger male twins, shown in Fig. 7, are virtually

identical; there were more very large twins in 1936-55, that would have been taken by CS in 1971-81, and more very small twins in 1971-81 that were live born due, presumably, to improved obstetrical techniques.

Table 5 - Socioeconomic indicators for the twins and spouses in the six completed birth-year cohorts who completed all questionnaires (percentages)

Years of education	0-9	10-11	HS	13-15	Coll.	Grad.	N
Males	2	4	41	22	16	15	2,449
Females	1	3	49	24	15	9	3,133

Occupational code[a]		1	2	3	4	5	6	7	8	N
Twins	Males	10	13	21	11	29	12	4	0	2,462
	Females	2	16	19	28	5	11	5	14	3,147
Spouses	Males	11	14	21	12	27	12	3	0	2,469
	Females	2	15	16	23	4	9	3	29	1,857

Family income (in $1,000s)	0-10	10-20	20-30	30-40	40-50	50-75	75-up	N
Males	5	16	26	22	13	11	5	2,367
Females	8	20	26	20	13	9	5	2,972

[a] The Occupational Code is from Hollingshead and Redlich [21]; #1 is professional, #2 is managerial, #7 is unskilled labor, #8 is homemaker.

Social Class and Education

Table 5 shows that 5% of the adult Registry twins did not complete high school, 45% stopped with high school graduation, and about 27% are college graduates. For the male twins, and the spouses of female twins, the most populous Hollingshead socioeconomic status (SES) categories are #3 (decorator, insurance agent, manager), #4 (bank clerk, farmer, Army non-com.), and #5 (hair stylist, locksmith, machinist.) Ten percent of the male twins (11% of the husbands) are professional people (SES #1) while some 16% of both groups are in category #6 (bartender, machine operator, meter reader, etc.) or #7 (laborer, car washer, welfare recipient). The modal combined family income was $20 to $30 thousand, about 25% earned less than $20 thousand, and about 15% had a combined income of more than $50 thousand. Thus, the Minnesota Twin Registry includes a broad cross-section of this north central state with greater representation of less well-educated, less affluent, working class and rural citizenry than is common among volunteer samples participating in psychological research.

These 29 to 52 year old twins averaged about 13.5 years of education, just over 2 years more than their parents received. The correlation between mother's and father's years of education was 0.53 for 269 pairs whose parents both completed

BQs; the twins' estimates of these parents' education were accurate enough to yield a spousal correlation of 0.52. The correlation between mothers' and fathers' education as reported by some 2,800 twin pairs was 0.55.

Thus, it appears that there was fairly strong assortative mating in the parental generation, considerably stronger than in the twins' generation where the correlation between twins and their spouses is only 0.37. A similar decrease in spousal correlation, from 0.86 to 0.52 over about one generation, has been reported for a large sample of Norwegian male twins [36]. Years of education completed by both male and female Registry twins correlated 0.48 with their mothers' and 0.52 with their fathers' educational attainment.

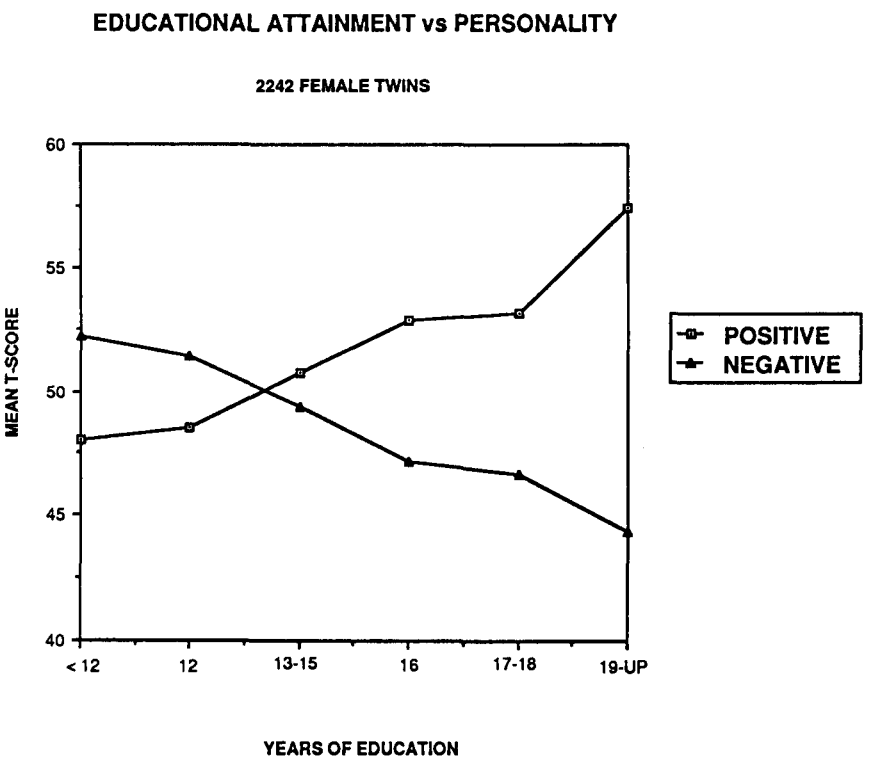

Fig. 8. Scores on Positive Emotionality (extraversion) and Negative Emotionality (neuroticism) as a function of years of education for 2,242 female twins born from 1936 to 1955. The ordinate is in T-score units (mean = 50, SD = 10). The correlation for males is slightly higher than for the females shown here.

Some 2,200 female and 1,100 male twins completed the Multidimensional Personality Questionnaire (MPQ) [38,40] and it was found that the super-factors, Positive and Negative Emotionality, vary systematically with educational attainment. As shown in Fig. 8, Positive Emotionality (PE: a kind of "talent for happiness",

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often called Extroversion) is about one SD higher in women with doctorates than in those who did not complete high school; the correlation between educational attainment and PE is 0.20 in both sexes. Negative Emotionality ("talent for misery" or Neuroticism) also varies systematically with educational attainment but in the opposite direction; the correlation is −0.20 in women and −0.25 in men.

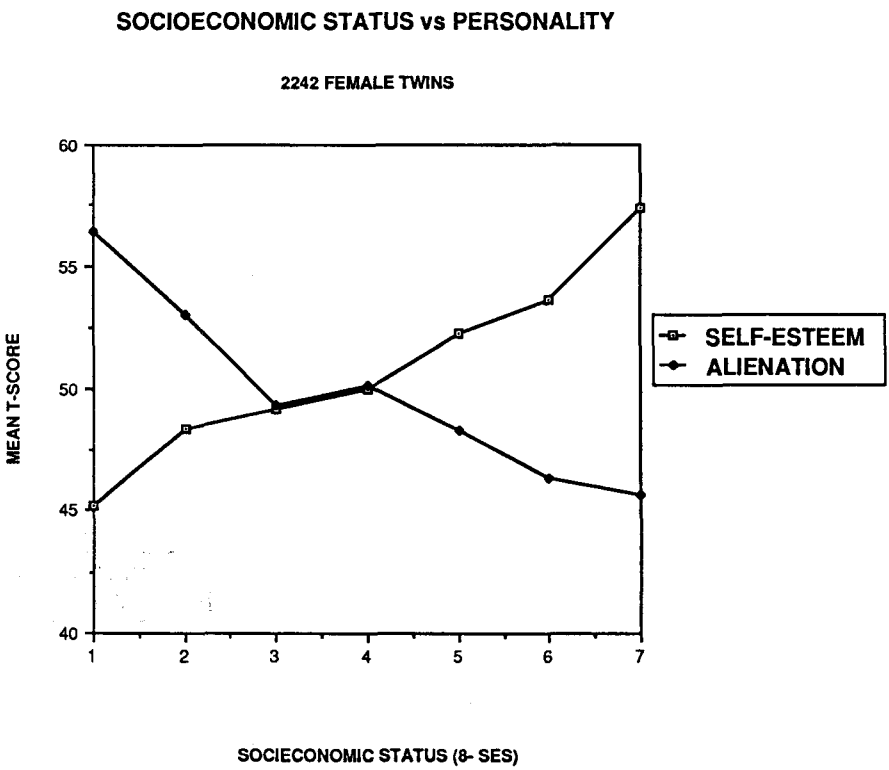

Fig. 9. Scores on Alienation and Self Esteem as a function of Socioeconomic Status (inverted so that 7 = professional). Ordinate is in T-score units. Male correlations are slightly higher.

The twins averaged a higher SES than their fathers, 4.14 vs 3.83 for 2,369 male twins, and 4.21 vs 3.85 for 2,643 females. These differences, while small, were highly significant with these large samples. The correlation with the fathers' SES was 0.35 for males, and 0.27 for females. SES, which is correlated about 0.60 with years of education, also showed similar personality correlates. As illustrated in Fig. 9, for example, low SES female twins were about one SD lower than high SES twins on a questionnaire measure of Self Esteem and about one SD higher on the Alienation scale of the MPQ: the correlations were 0.20 and −0.18, respectively, for women; 0.28 and −0.31, respectively, for men. (Twins who identified themselves as homemakers were excluded from these computations since the socioeconomic status of this category is ambiguous).

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Table 6 - Within-pair correlations on demographic variables[a]

	MZ twin pairs		DZ twin pairs		OS twin pairs
	MM (N=433)	FF (N=392)	MM (N=632)	FF (N=571)	(N=380)
Years of education	0.64	0.66	0.44	0.50	0.40
Occupational status	0.59	0.53	0.38	0.32	0.24
Spouse's occ. status	0.28	0.38	0.06	0.23	−0.01
Gross family income	0.53	0.41	0.37	0.25	0.29

[a] Intraclass correlations used for same-sex twins, product-moment correlations for opposite-sex pairs.

The intrapair twin correlations for SES and education are shown in Table 6 and indicate significant effects of both genetic and shared environmental influences. The Falconer heritabilities range from 0.30 to 0.44.

Table 7 - Marital and parental status of all twins who returned a Biographical Questionnaire

	Ever married	Ever divorced	Never married	Total
Male twins				
MZ	730	133 (18%)	146 (17%)	876
DZ	665	129 (19%)	128 (16%)	793
OS	340	73 (21%)	42 (11%)	382
Female twins				
MZ	1,128	207 (18%)	156 (12%)	1,284
DZ	1,024	223 (22%)	117 (10%)	1,141
OS	349	93 (27%)	30 (8%)	379

Number of offspring[a]

	Parents	Offspring	Ratio
Male twins	2,036	3,701	1.82
Female twins	2,647	5,311	2.01

Total: 4,683 twins produced 9,012 offspring, ratio = 1.92

[a] Ever-married twins only.

Marriage, Offspring, and Divorce

Some 17% of MZ twins, and 16% of DZs, had never married (Table 7). Once married, however, there is a slightly lower divorce rate among MZ twins (18%) than among DZs (19%). Nearly 1/5 of these twins, aged 29 to 52 at the time of

reporting, had produced no offspring. The total number of living children produced by all 4,683 twins is 9,012, giving a reproductive ratio of 1.92. Separately by birth-year cohort, we computed the correlation between number of offspring and the number of siblings in the family in which the twins were reared; the root-mean-squared weighted average of these correlations was 0.13 for both males and females, small but statistically significant for these large samples.

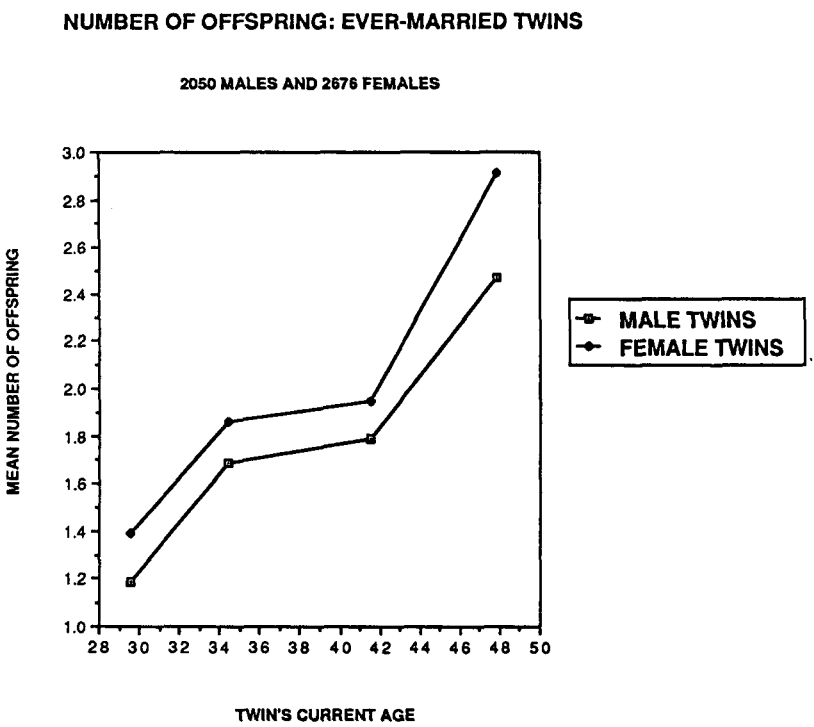

Fig. 10. Number of offspring as a function of the age of the (twin) parent. Although these twins are from 10 birth-year cohorts, their ages at time of data collection yielded only 4 data points. The younger twins started their families later and will probably have smaller families, on average, than the older twins.

Is Fecundity Heritable?

The average number of offspring increases steadily over the full age range of these Registry twins (see Fig. 10) even though the 4 oldest cohorts were aged 45 to 50 at time of testing. This suggests that there are two effects working additively; the younger twins have not yet completed their families while the older twins had larger

families on average than the younger ones will ever have. At the time these older twins were beginning their families, the frequency of newborn infants in families of size N in Minnesota was a linear-decreasing function of N (see Fig. 11). Over the ensuing 20 years, as the younger Registry twins were beginning their families, this function became increasingly sigmoid; family size decreased rapidly during this period while the age of Minnesota mothers at primiparity increased.

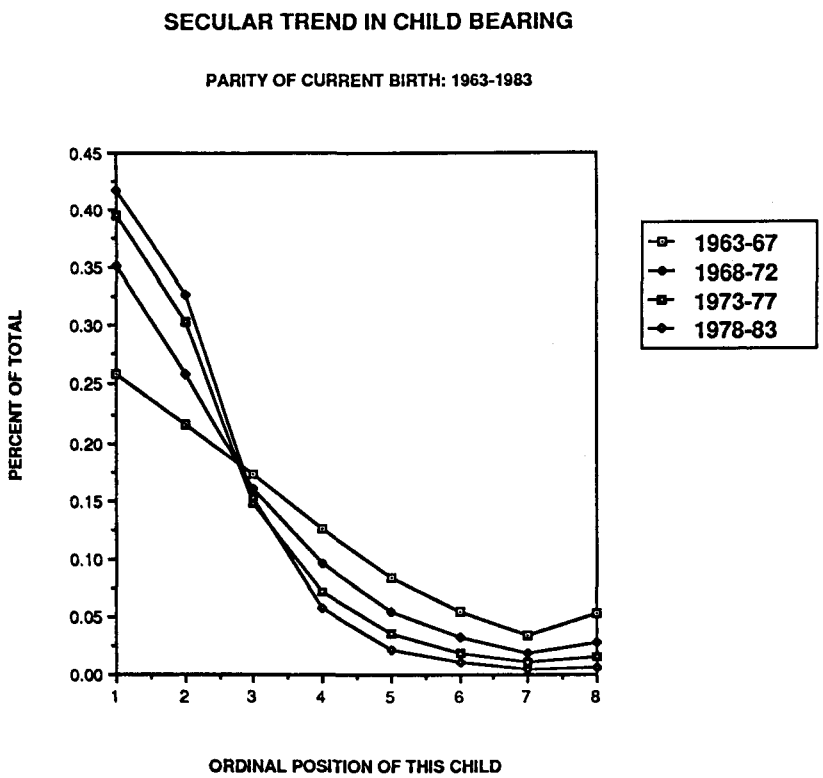

Fig. 11. Secular trend in parity of current birth, 1963 to 1983, all live births, from Minnesota Health Department records. In 1978-83, 42% of all births were first-born children, as compared with 26% in 1963-67. These curves show a regular trend toward smaller families over the 20-year period.

To compute within-pair similarity in number of offspring, independent of this confounding secular trend, requires that we somehow remove the trend from the raw data. We did this in two ways. For each of the 10 birth-year cohorts, and for the sexes separately, we computed the mean and variance of number of offspring and also the within- and between-mean squares. We first excluded all pairs in which either twin had never been married, ensuring that both members of the included pairs had been equally "at risk" for the production of offspring.

We then divided each within- and between-mean square by the total variance for that cohort, obtained the overall within- and between-mean squares as the N_i-weighted average of the 10 values (N_i = number of pairs in the *ith* cohort), and computed the grand average intraclass correlation. Our second method of removing the secular trend was to convert each twin's number of offspring to a deviation score by subtracting that cohort's mean number of offspring and dividing by that cohort's standard deviation. We then computed the overall intraclass correlation from these deviation scores. Both sets of correlations are given in Table 8.

Table 8 - Weighted mean intra-class correlations for number of offspring[a]

	MZ twin pairs		DZ twin pairs		OS twin pairs[b]
	MM (N=317)	FF (N=482)	MM (N=281)	FF (N=446)	(N=314)
Method 1	0.29	0.32	0.12	0.18	0.09
Method 2	0.30	0.36	0.14	0.26	0.11

[a] Only pairs in which both twins had been married at least once were included in the analysis. The secular trend of offspring vs parental age was removed in two ways (see text) before computing the correlations.
[b] OS twin values are product-moment correlations.

The average correlation for number of offspring, weighted by sample size, is 0.322 for MZ twins and 0.160 for DZs, yielding a heritability of 0.32. Since both parents play a role in determining the number of offspring, except when one spouse is biologically infertile, the upper limit of heritability in fecundity would seem to be about 0.5. Thus, an estimated heritability as high as 0.32 must be regarded as substantial and, perhaps, surprising.

Is the Risk of Divorce Heritable?

Again limiting consideration only to ever-married twins, the divorce rate for these 30- to 50-year-old twins was more than double the rate for their parents and the risk of divorce in twin offspring of divorced parents was about 46% higher than for offspring of parents who had not divorced (Table 9). Cotwins of divorced MZ twins were nearly three times as likely to be divorced themselves than were cotwins of still-married twins. The increase in risk for DZ cotwins, 46%, was about 1/4 that for MZ pairs but also statistically reliable.

When divorce rate (proportion ever divorced) is plotted against age as in Fig. 12, the inverted U-shaped curve appears to be the sum of two opposing secular trends; the younger twins are moving through the period of greatest divorce risk while the older twins, nearly through the risk period, display the higher threshold

Table 9 - Concordance for divorce among (ever-married) twin pairs and among twin individuals and their parents[a]

	MZ twins		DZ twins	
	MZ twin offspring		DZ twin offspring	
	Not divorced	Divorced	Not divorced	Divorced
Parents				
Not divorced	941	229	1,292	368
Divorced	68	26	106	54
	$\chi^2 = 3.5$ ($P \approx 0.05$)		$\chi^2 = 11.0$ ($P < 0.001$)	
	P(D|parents D) = 0.277		P(D|parents D) = 0.338	
	P(D|parents not D) = 0.196		P(D|parents not D) = 0.222	
Increased risk if parents are divorced				
MZs = (0.277 − 0.196)/0.196 = 41%			DZs = (0.338 − 0.222)/0.222 = 52%	

	MZ twins		DZ twins	
	Twin B		Twin B	
	Not divorced	Divorced	Not divorced	Divorced
Twin A				
Not divorced	433	68	554	158
Divorced	77	55	136	65
	$\chi^2 = 52.7$ ($P < 0.001$)		$\chi^2 = 8.7$ ($P < 0.001$)	
	P(D|cotwin D) = 0.413		P(D|cotwin D) = 0.306	
	P(D|cotwin not D) = 0.143		P(D|cotwin not D) = 0.210	
Increased risk if cotwin is divorced				
MZs = (0.413 − 0.143)/0.143 = 189%			DZs = (0.306 − 0.210)/0.210 = 46%	

[a] If parents are divorced, offspring risk is 40%-50% higher than for offspring of non-divorced parents. Risk of divorce if cotwin is divorced increases from 14% to 41% for MZ twins and from 21% to 31% for DZ twins.

for divorce characteristic of their generation. The lower curve in Fig. 12 represents the proportion of the parents of the twins in each cohort who had ever been divorced from each other. Having remained married long enough to produce the twins, these parents are somewhat selected for lower than average risk but their curve illustrates the lower divorce rate (higher threshold) of the parental generation. It seems likely, had we recruited another 10 birth-year cohorts of older twins, the oldest of which would be about the age of the parents of our youngest twins, that the extended right side of the upper curve in Fig. 12 would have merged into the parental divorce-rate curve, ie, the left side of the lower curve in the figure.

In any case, just as for assessing twin similarity in number of offspring, above, these secular changes in divorce rate pose a problem since they might tend to inflate twin concordance. For a dichotomous variable such as divorce, there is no wholly satisfactory way to partial out the secular variation. The main age-related change in twin divorce rate is the increase from 14 to 22% for twins aged 29 to

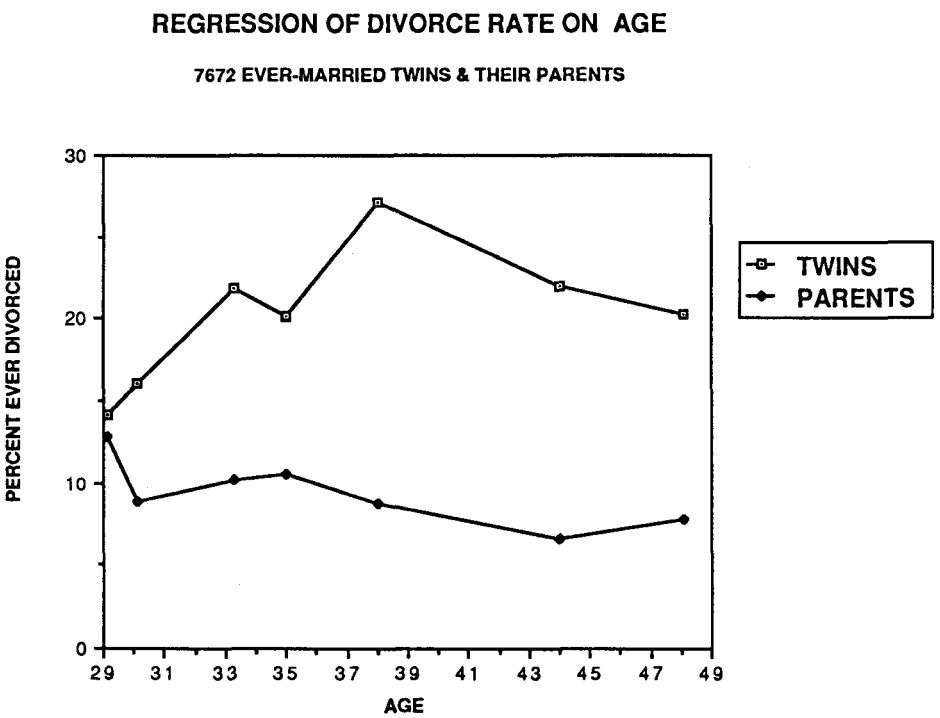

Fig. 12. Regression of divorce rate on age for ever-married twins and their parents. For the Parents' curve, the abscissa represents the age of their twin offspring; the parents of the younger twins were some ten years older than the age of the oldest twins. The right half of of the twins' curve, together with the curve for the parents, illustrates the secular increase in rate of divorce. The left half of the twins' curve illustrates the increase in cumulative divorce risk as the twins move through the risk period.

33. Therefore, all twins younger than 33 years were omitted from the calculations in Table 9 although, as it turned out, the MZ correlation was unchanged by this omission.

Conventional wisdom would suggest that the increase in risk for divorce among offspring of divorced parents is environmentally transmitted. Children from broken homes are expected to be less well-adjusted, more prey to later marital problems. Moreover, they have been raised by role-models whose marriages are characterized by conflict and intransigence and who "solved" these problems by recourse to divorce. Such reasoning would predict an increased risk among children of divorce. Only a genetic model, however, comports with all the data, eg, the fact that the increase in divorce risk for DZ cotwins of divorced probands is about equal to the

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increased risk for offspring of divorced parents, and less than half the increased risk for cotwins of divorced MZ twins. Therefore, a reasonable interpretation of the parent-offspring correlation is that the children of divorce are more at risk for divorce themselves largely because of the genetic proclivities that they inherited from their affected parents.

Table 10 - Self-reported anthropometric measures on the tested twins and families of the first 6 birth-year cohorts

	N	Height (in)		Weight (lb)		Ponderal index	
		Mean	SD	Mean	SD	Mean	SD
MZ twins							
males	384	70.3	2.9	176.1	24.8	12.59	0.57
females	569	64.4	2.6	136.1	26.8	12.61	0.70
DZ twins							
males	361	70.3	2.7	176.1	26.7	12.60	0.53
females	559	64.5	2.6	135.7	27.2	12.64	0.70
Spouses							
males	482	70.8	2.6	184.4	28.4	12.49	0.56
females	414	64.5	2.4	137.0	23.8	12.59	0.68
Siblings							
males	67	69.8	3.6	181.3	30.3	12.38	0.52
females	104	64.9	3.3	147.1	32.4	12.39	0.79
Parents							
males	112	69.9	2.9	186.2	24.3	12.28	0.51
females	122	64.5	2.9	150.6	23.9	12.17	0.68
Offspring							
males	116	70.5	3.1	169.4	24.0	12.97	0.61
females	175	64.9	2.6	130.0	19.9	12.86	0.64

Anthropometric Data

Self-reported heights and weights (Table 10) indicate that the participating MZ and DZ twins do not differ in stature nor are the twins shorter on average than their singleton siblings or parents. The twins weigh slightly but significantly less than the contemporaneous spouse sample but, as expected, the young-adult offspring average thinner than their parents.

Intra-class correlations of these variables, for all twins who returned the BQ, are given in Table 11. The correlations for self-reported height are slightly lower than those found whe stature is measured in the laboratory [28].

With respect to birth weight (obtained directly from birth records), the DZ correlations are as high as for MZ twins. Birth weight is, of course, largely determined by gestational age at parturition, ie, by an environmental influence common

Table 11 - Intra-class correlations of Registry twins on certain anthopometric variables[a]

	MZ twin pairs		DZ twin pairs		OS twin pairs[b]
	MM	FF	MM	FF	
N	318	471	288	407	221
Birth weight					
Uncorrected	0.73	0.71	0.56	0.70	0.64
Corr. for gest. age	0.57	0.60	0.58	0.60	0.47
Gest. age = 40 wk	0.65	0.65	0.56	0.64	0.42
(N)	(163)	(234)	(166)	(234)	(115)
N	435	638	392	570	380
Height (self-reported)	0.86	0.90	0.44	0.44	0.40
Weight (self-reported)	0.76	0.79	0.32	0.31	0.29
Ponderal index	0.73	0.78	0.30	0.36	0.38

[a] The precision of the estimates is high due to large N, eg, the 95% confidence interval for the MZ female correlation for height runs from 0.884 to 0.914.

[b] The values for the OS pairs are product-moment correlations, male vs female.

to both twins. We attempted to remove the effect of gestational age by converting each weight to a standard score relative to all the twins of that sex and twin type who were born at the same gestational age as the index case. Within-pair correlations based on these corrected scores are somewhat smaller than before but still as large for DZ as for MZ pairs. Since about half the pairs were born during week 40 of gestational age, we also computed the correlations of (uncorrected) birth weight for this group separately. Once again, there is no suggestion of an MZ:DZ difference, ie, no evidence of heritability of birth weight. Vlietinck et al [41], modeling with LISREL the birth weight of 1,855 Belgian twin pairs born since 1964, attributed 22.5% of the variance to additive genetic factors; perhaps their prospective study achieved more accurate estimates of gestational age than were available to us. In any case, it is notable that birth weight is the only dependent variable we have so far encountered on which DZ twins are as similar as MZ twins for both sexes, and the only variable for which shared environment is the major source of phenotypic variance.

Frequency of Contact

As can be seen in Table 12, female twins stay in closer touch than male twins do and MZ twins speak together, either in person or by telephone, significantly more frequently on the average than do DZ twins. Thus, for example, 29% of MZ females, and 23% of MZ males, speak together daily, as compared with 15% and

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Table 12 - Reported frequency of contact of tested Registry twins

Index category	Index	Males			Females		
		MZ	DZ	OS	MZ	DZ	OS
Twins live together	6	5%	2%	1%	3%	1%	1%
Speak together							
Daily	5	18	6	3	26	14	2
Weekly	4	34	26	19	40	30	17
Monthly	3	26	30	32	22	32	34
On holidays	2	7	17	25	3	9	25
Seldom	1	10	20	21	4	14	21
Mean index value		3.6	2.9	2.6	3.9	3.2	2.6

8% of female and male DZ pairs, respectively.

More detailed assessment of perceived closeness was conducted on twin cohorts born in 1946 and 1952. Approximately 100 pairs each of MZ, SS-DZ and OS-DZ twins responded to a 14-item questionnaire containing three clusters of inter-correlating items concerned with amount of contact, degree of closeness and intimacy, and perceived similarity. MZ pairs were in closer contact and saw themselves as more similar than either group of DZ twins. MZs also described themselves as closer to one another than did the DZ pairs; this difference was small but consistent, appearing for both sexes on all five questions in the Closeness cluster. Over the entire group, Closeness correlated about 0.40 with Contact and about 0.55 with perceived Similarity.

Rose et al [34] have argued that the greater similarity in personality of adult MZ than DZ twins may be a consequence of this greater frequency and intimacy of contact. The present findings corroborate once again the greater closeness among MZ twins and the strong correlation between closeness and similarity. However, we continue to believe that similarity leads to intimacy, rather than the other way about, in part because the obverse hypothesis leaves intimacy unexplained while similarity can be explained genetically.

RECRUITMENT BIAS

Studies of volunteer twins tend to involve twice as many female as male pairs and twice as many MZ as DZ pairs [29]. This suggests the possibility that pairs who agree jointly to participate may not be representative of twins in general. In a later paper [27], we argued that when twins are asked to participate in laboratory studies, pairs in which there are marked differences in such salient traits as physical appearance, intelligence, extroversion, and the like, might be relatively harder to recruit and that DZ twins, especially, might therefore be selected for within-pair similarity. Evidence from our own work was offered indicating that the DZ sample

included fewer obese individuals than were in the MZ sample, as evidenced by a smaller variance in weight and ponderal index.

A recent report on a large sample of Norwegian twins [36] suggests that recruitment bias might not be a problem, at least in the case of studies in which the data are collected by mail. Several thousand male twins who had been given IQ tests in connection with compulsory military service years earlier were sent biographical questionnaires. Of those pairs with complete IQ scores and known zygosity, 65% of the individual twins returned the questionnaires and it was thus possible to compare the similarity in IQ of the MZ and DZ pairs who were concordant for participation with that of the pairs where one or both members did not participate. As might be expected, a higher proportion of MZ than DZ pairs were concordant for participation (or for nonparticipation) but no systematic differences were found in IQ heritabilities estimated for the concordant and discordant subsamples, ie, no evidence was found for a significant selection bias in this mailed questionnaire study.

Our twin registry recruitment was designed to examine the same question in a different way. Individual participants varied in cooperativeness from those who returned only the BQ, and that after two prompts, to those who returned all test materials with no prompts. A subgroup of twins, 61% female and 67% MZ, were classified as "Volunteers." These were twins who had heard of our work and had contacted us asking to be included in the project. Those who were in the age range of the Registry were sent the same test materials even though most of them had not been born in Minnesota. Those Volunteers who returned both the BQ and the tests without prompting, 328 of them, were classified separately to indicate their unusual eagerness to participate.

We then examined the relationship of ease of recruitment to a variety of demographic and personality variables. The Volunteers were significantly better educated and had a higher SES than the rest of the Registry sample. With respect to the MPQ personality variables, they were higher on Social Potency, Social Closeness, and Positive Emotionality, lower on Alienation, Traditionalism, and Negative Emotionality. They had higher Self Esteem and expressed stronger Cultural, Political, and Literary interests. The males were less interested in Hunting and Professional Boxing or Wrestling and both sexes were less interested in Farming and Practical (blue-collar) occupations than the twins who required prompting. The Volunteers were higher on self-rated "school intelligence" and, since they became volunteers by being independently aware of our research and contacting us on their own initiative, it seems likely that, as a group, they differed from the rest of the sample in IQ and its many correlates.

Those non-volunteer twins who also required no prompting and who comprised the majority of the Registry, however, did not differ substantially from the remainder of the sample. A few statistically significant differences appeared because of the large sample sizes; thus, the non-prompted twins were significantly more interested in literary and cultural pursuits, and less interested in farming, than the twins who required prompting but the mean differences were less than 4/10 of a standard deviation. The within-pair correlation for our 9-point cooperation code was 0.53

for 687 MZ pairs and 0.38 for 551 DZ twin pairs. The Volunteer twin pairs were more similar, within pairs, on a variety of personality, interest, and demographic variables than were the bulk of the Registry twins. However, non-volunteer pairs in which both cotwins participated fully without prompting were not significantly more similar in personality or interests than tested twins who required prompting. The most cooperative twins did not report more frequent contact with their cotwins nor were they more similar in education or in SES than pairs in which one or both cotwins refused to be tested.

Table 13 - Numbers of Registry twin pairs from the first 6 birth-year cohorts who completed the full test battery[a]

	No. concordant pairs			No. discordant pairs		
	MZ	DZ	Total	MZ	DZ	Total
Males	150	125	275	76	122	198
Females	281	235	516	42	86	128
Total	431	360	791	118	208	316
Female pairs		65.2			40.5	
MZ pairs		54.5			37.3	

[a] The concordant pairs, on the left, are two-thirds female but the proportion of MZ pairs is about equal to that of the parent population. Of the smaller group of discordant pairs, on the right, a majority are male and DZ pairs out-number MZ pairs by nearly two to one.

As can be seen in Table 13, the 791 SS pairs from the first 6 years who were concordant for completing all testing (excluding all volunteer twins) included 54.5% MZ pairs (vs about 48% in the population) and 65.2% female pairs (vs about 50%.) Thus, while males are under-represented in our sample of tested twins, the tested MZ and DZ pairs are more nearly equal proportions of the MZ and DZ pairs resident in Minnesota. Table 14 shows that the concordant and discordant pairs did not differ in within-pair similarity on years of education or SES. (Note, however, that the total variance for weight was significantly larger for discordant than for concordant female pairs.)

Our data, therefore, corroborate those of Tambs et al [36] indicating that, when adult twins, most of them living apart with their own families, are solicited to participate by mail in a questionnaire study, the pairs who are concordant for participation are not markedly different, nor more similar within-pairs, on demographic or psychological variables than pairs in which one or both twins refuse participation. This is true even though the participating pairs will include a higher proportion of females than males and of MZ than DZ twins.

Our data do indicate that twins who are so eager to participate that they volunteer without solicitation may not be representative of twins in general, better informed and perhaps more intelligent on average. This suggests, but does not prove, that twins who respond to newspaper advertisements soliciting twins for psychological research might also be atypical.

Table 14 - Intra-class correlations (R), within- and between mean squares (WMS, BMS) for 3 variables comparing same-sex pairs from the first 6 birth-year cohorts who both completed testing with pairs from which only one twin completed testing

		No. concordant pairs		No. discordant pairs	
		MZ	DZ	MZ	DZ
Education					
Males	R	0.72	0.41	0.80	0.40
	WMS	1.65	3.83	1.58	3.82
	BMS	10.11	9.10	14.51	8.85
	N	147	124	58	84
Females	R	0.72	0.53	0.59	0.66
	WMS	1.29	1.92	2.03	1.55
	BMS	8.00	6.29	7.80	7.52
	N	275	230	36	56
Socioeconomic status					
Males	R	0.61	0.24	0.63	0.44
	WMS	1.13	2.15	0.97	1.57
	BMS	4.71	3.52	4.23	4.08
	N	150	125	59	86
Females	R	0.43	0.27	0.45	0.14
	WMS	2.54	3.12	2.68	4.43
	BMS	6.40	5.44	7.07	5.84
	N	277	233	36	57
Reported weight					
Males	R	0.79	0.37	0.76	0.33
	WMS	1.15	4.42	1.28	5.03
	BMS	9.59	9.60	9.36	10.08
	N	146	124	57	83
Females	R	0.84	0.33	0.86	0.20
	WMS	1.28	3.85	1.54	6.12
	BMS	14.67	7.61	21.01	9.22
	N	264	224	34	55

It is important to emphasize, however, that the recruitment bias discussed in Lykken et al [27] may still be important in relation to studies where the twins are required to present themselves together, in person, for testing. In contrast to mailed questionnaire studies, the prospect of joint in-person assessment seems much more likely to intimidate one or both members of twin pairs who are especially different on one or more salient traits and should therefore bias recruitment in favor of more similar pairs. Because they are more likely to differ on such traits, this bias will be greater for DZ than for MZ twins.

CONCLUSIONS

Construction of a birth-record-based twin registry is a feasible undertaking in the United States even though the birth-to-death records on our citizens are less detailed and less centralized than in some European countries. Without undue expense we have located more than 80% of the still intact twin pairs and obtained biographical (including zygosity) data from 80% of those located. It should be noted that the large registries in Finland and in Sweden [8] obtained questionnaire returns from 89% and 83%, respectively, of the individual twins solicited. Whether this achievement reflects cultural differences or a more skillful solicitation than ours cannot be decided on the available evidence. In any case, our Registry sample seems broadly representative demographically of the parent population and the twin pairs concordant for participation appear to be unselected for similarity in education, SES, or a variety of personality and interest factors.

Preliminary analyses of the data so far collected, on some 2,400 twin pairs, suggest that the broad heritability of socioeconomic status, years of education, and present income level ranges from about 0.30 to 0.40. Not surprisingly, education and SES are correlated positively with Positive Emotionality and Self Esteem, negatively correlated with Negative Emotionality and Alienation. There is a weak but significant tendency for twins from larger families to produce more offspring themselves. The within-pair correlation for number of offspring, for MZ pairs where both twins have been married, is about 0.30, which should be compared with a maximum possible correlation on the order of 0.50. Similarly, the risk of divorce among MZ twins whose cotwin is divorced is about 0.41 which, since divorce like procreation is a two-person game, should probably be compared with a maximum possible risk of about 0.50. This risk is nearly 3 times the risk for MZ twins whose cotwin has never been divorced. Since all of these variables – attained SES, years of education, family income, number of offspring, risk of divorce – are plainly complex, multifactorial outcome variables, it is clear that this evidence of significant heritability implies that many of the diverse personality, interest, and aptitude variables that act together to influence these outcomes are themselves substantially influenced by genetic variation.

When completed by the end of 1990, the Minnesota Twin Registry will include some 8,000 pairs of Minnesota-born, SS and OS twins then aged 33 to 54, plus some 1,200 pairs of male twins aged 8 to 18. Demographic and zygosity information will be available on most of these twins and personality and interest test data on about half of them. We are impressed with the need for such large numbers, both because they become rapidly smaller as one focusses on special groups (eg, pairs in which at least one twin has a history of headache), and because the more interesting questions must be addressed with the precision of large samples (eg, the study of epistasis or emergenic traits [19,24,26,28,30]). It is our intention to maintain this Registry, perhaps to extend it to include both older and younger twins, and to make it available (under rather strict controls) for use by other investigators.

We shall not release names or addresses of any Registry participants except in unusual circumstances. All contacts with Registry twins and their families will

be made, at least initially, through us. Requests to make use of either random or selected samples should be directed to one of the authors of this article and should include a reasonably detailed explanation of what is to be requested of the participants, what compensation will be provided them, and the scientific purpose of the proposed research. The Registry Research Committee will consider each request; subject to the approval of the Registry Committee, and of our University's Committee on the Use of Human Subjects in Research, we will do a mailing to all or an appropriate subset of the Registry twins describing the proposed project and inviting their participation.

Wherever possible, all contact with the twins will be through us. In rare circumstances, eg, where the project requires face-to-face contact between participants and the investigator, we may – with the twins' prior approval – provide investigators with the twins' names and addresses. In all cases, investigators must agree to assume our costs as intermediaries, to maintain the confidentiality of the participants, and to provide us with both a summary of findings and, where requested, with individual data that we can add to the Registry data base.

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