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Concordance in physical growth for monozygotic and dizygotic twins

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Summary. Heights and weights were analysed for 636 twins who had been repeatedly measured from birth to 4 years. MZ twins were less concordant for birth weight than DZ twins, principally as a result of a few MZ pairs who exhibited very large differences. By one year of age, however, MZ twins had become more concordant for weight (R_{mz}=0·87) while DZ twins moved further apart (R_{dz}=0·55). For height, at birth, the MZ correlation was 0·58 while the DZ correlation was 0·82, but by 2 years, the MZ correlation reached 0·89 and the DZ correlation regressed to 0·58. The actual size differences within pairs followed a parallel course—for MZ twins, the differences became smaller following birth, whereas the DZ differences became larger. The results are discussed in terms of (*a*) prenatal influences that differentially affect birth size within MZ pairs and DZ pairs, and (*b*) the rapid convergence of each twin on his genetic growth curve.

1. Introduction

In recent years, the Louisville Twin Study has been recruiting newborn twins for participation in a longitudinal study of growth and development. The twins have been measured periodically during childhood, and a set of growth standards for twins has been developed (Wilson, 1974).

The present paper appraises the degree of concordance in physical growth for monozygotic (MZ) twins and dizygotic (DZ) twins. The genotype is expected to play a substantial role in growth, leading to greater concordance for MZ twins, but this expectation is tempered by several other factors which would affect birth size and subsequent growth. The twins in each pair, whether MZ or DZ, share many prenatal influences and are delivered at the same gestational age, which should increase their similarity in birth size. For DZ twins, this might make them more concordant at birth than predicted on the basis of genetic overlap alone.

By contrast, about 70 per cent of MZ twins are born with monochorionic placentas, and most of these placentas are subject to varying degrees of vascular anastomosis (Bulmer, 1970; Strong and Corney, 1967). If the anastomosis results in unequal nutrition being supplied to the twins, it would accentuate the within-pair differences in birth size. Naeye, Benirschke, Hagstrom and Marcus (1966) have reported greater within-pair variability for monochorial twins, and on occasion a dramatic example of this transfusion syndrome may be found (e.g. Falkner, 1966).

From this perspective, a sample of MZ twins might exhibit less concordance for birth size than would be expected from the common factors of genotype, gestational age, and prenatal environment. In postnatal growth, however, MZ twins would be expected to converge while DZ twins would diverge until an intermediate level of concordance was reached.

2. Materials and methods

The physical growth data are based on a sample of 636 white twins, drawn from the entire socio-economic range of the metropolitan Louisville area. The twins were measured at visits scheduled at 3, 6, 9, 12, 18, 24, 36 and 48 months of age (±1 week). There is slight attrition at older ages due to a few families withdrawing from the study, and the fact that not all the twins have yet reached their fourth birthday. No twins older than 3 months of age were added to the study, so the sample is truly longitudinal (Tanner, 1951) but with a few instances of missing data.

The methods of measurement have been described in detail elsewhere (Wilson, 1974). Weight was measured on a balance scale from 3 to 24 months, and on a platform scale at later ages. Birth weight was obtained from the twin's birth certificate. Height was measured as recumbent length up to 24 months, and as standing height thereafter. Where available, measures of birth length were obtained from hospital records. In general, the birth length data were less complete and less precise than the length measures at subsequent ages.

The determination of zygosity for same-sex pairs was based on bloodtyping for 22 or more antigens (Wilson, 1970); if the twins were discordant for any antisera tests, they were classified as DZ. For technical and psychological reasons the bloodtyping was deferred until the twins were 3 years old, so most of the data had been collected before zygosity was established. Placental data were not available for most of these twins.

3. Results

An initial comparison was made between MZ twins and DZ twins for weight (table 1) and height (table 2). The means and SDs for weight were very close at each age, with only one significant MZ/DZ difference throughout the 4-year period.

Age	MZ Mean	DZ Mean	MZ SD	DZ SD	No. of twins MZ/DZ
3 months	2·53	2·58	0·46	0·52	318/318
6 months	5·31	5·38	0·76	0·70	256/240
9 months	7·22	7·14	0·92	0·91	286/268
12 months	9·50	9·45	1·15	1·10	292/284
1·5 years	10·59	10·78	1·25	1·34	280/270
2 years	11·66	11·93*	1·29	1·50	286/274
3 years	13·82	13·85	1·56	1·62	274/276
4 years	15·79	15·70	1·82	2·08	232/228

*DZ twins significantly heavier ($P<0{\cdot}05$ with $df=558$).

Table 1. Weight (kg) of MZ twins and DZ twins from birth to four years.

Age	MZ Mean	DZ Mean	MZ SD	DZ SD	No. of twins MZ/DZ
Birth	47·3	48·4*	2·81	3·39	176/158
3 months	57·8	58·2	2·72	2·88	258/240
6 months	65·2	65·1	2·56	2·92	286/268
9 months	69·8	69·9	2·67	2·92	280/274
12 months	74·1	74·0	2·79	3·13	292/284
1·5 years	80·4	80·4	2·92	3·59	280/270
2 years	85·1	85·7*	3·24	3·52	286/274
3 years	92·9	93·4	3·55	3·78	274/276
4 years	100·5	100·8	4·28	4·22	232/228

*DZ twins significantly larger at birth ($P<0{\cdot}001$); also at age 2 years ($P<0{\cdot}05$).
Note. Recumbent length to age 2 years, standing height thereafter.

Table 2. Height (cm) of MZ twins and DZ twins from birth to four years.

The height measures were also quite similar for MZ twins and DZ twins. The latter did average about 1 cm longer at birth, but the length advantage was not retained at subsequent ages. Since the birth length data were incomplete, this result is regarded as tentative until more complete data become available. DZ twins did display slightly greater variability in height than MZ twins at most ages, a probable result of the fact that twice as many zygotes are represented among the DZ twins.

Within-pair concordance for weight and height

The within-pair correlations were computed separately for MZ pairs, same-sex DZ pairs, and then for the complete DZ sample of same-sex plus opposite-sex pairs. The results are presented in table 3.

	Weight			Length/Height		
Age	MZ pairs	Same-sex DZ pairs	Total DZ pairs	MZ pairs	Same-sex DZ pairs	Total DZ pairs
Birth	0·61	0·70	0·68	0·58	0·82	0·69
3 months	0·75	0·63	0·60	0·75	0·72	0·68
6 months	0·80	0·62	0·58	0·78	0·65	0·64
9 months	0·83	0·50	0·50	0·82	0·59	0·60
12 months	0·87	0·55	0·54	0·85	0·69	0·70
1·5 years	0·87	0·56	0·60	0·89	0·70	0·71
2 years	0·89	0·55	0·60	0·89	0·58	0·63
3 years	0·89	0·52	0·57	0·92	0·55	0·61
4 years	0·86	0·50	0·55	0·94	0·60	0·61

Note. Number of pairs entering into each correlation may be obtained from tables 4 and 5.

Table 3. Within-pair correlations for twins on weight and height.

The MZ correlations at birth were comparatively small for weight and length; in fact these MZ twins were less concordant than same-sex DZ twins. Evidently the distinctive prenatal conditions which affect some MZ pairs did produce larger disparities in birth size and lower measures of concordance. As the analysis below will show, however, MZ twins were not uniformly more discrepant for birth size than DZ twins; the median size difference was essentially the same for both groups. But when large differences did occur, they were more frequent among MZ twins.

Following birth, the MZ correlations became increasingly larger for weight and height. Most of the increase occurred in the first year, as the prenatal effects were dissipated and the members of each MZ pair converged on a common growth curve. For height particularly, the convergence continued throughout the four-year period until the MZ correlations reached the mid-0·90's.

In contrast, the DZ correlations followed an opposite course; they were relatively large at birth but declined progressively with age until an intermediate level of concordance was reached. The DZ correlations for height stabilized at a slightly higher level than for weight; and if height is the more definitive marker of the genotype, these correlations would reflect the degree of genetic overlap produced among zygotes by within-pair gene segregation plus assortative mating.

Distribution of size differences within pairs

The actual size differences for the twins at each age were computed for each pair, and the empirical distribution of differences was obtained separately for MZ twins, DZ same-sex twins, and DZ opposite-sex twins. The results for weight are presented in table 4.

At birth, the average weight difference within pairs was essentially the same for all three groups, and even the 90th centile differences were comparable. At the extreme, however, the largest birth–weight differences were found among MZ pairs.

In the postnatal period, the most notable feature for MZ twins was the consistency of their centile values from 6 months to 3 years of age. The distribution of weight differences within MZ pairs remained constant during a period of growth in which the twins nearly doubled their actual weight. By contrast, the weight differences within DZ pairs became progressively larger with age.

The distribution of height differences for each group is shown in table 5. At birth, the median height difference was the same for all three groups, but the most extreme height differences were found among opposite-sex pairs and MZ pairs. Ten per cent of these twins differed at birth by more than 5 cm; only 3 per cent of same-sex DZ twins differed by this much.

Once postnatal growth was under way, however, the DZ same-sex differences became progressively larger while the MZ differences actually diminished. In the latter case, the median MZ height difference stabilized below 1·0 cm, and by age 3 years, fewer than 10 per cent of the MZ twins differed by as much as 2·5 cm. But among DZ same-sex twins, more than half the pairs displayed height differences in excess of 2·5 cm. Clearly, the age trends in growth were for convergence among MZ twins and divergence among DZ twins.

Birth size differences and later growth

Frequently the query is raised whether the twin heavier at birth remains consistently heavier than his co-twin at later ages. Accordingly, the number of pairs

Age	Type of pairs	No. of pairs	Mean	Centiles 50	90	97
Birth	MZ	159	0·30	0·24	0·62	0·93
	Same-sex DZ	107	0·31	0·28	0·59	0·80
	Opp.-sex DZ[a]	88	0·32	0·25	0·66	0·88
3 months	MZ	128	0·35	0·25	0·76	1·01
	Same-sex DZ	87	0·46	0·38	0·90	1·30
	Opp.-sex DZ	34	0·59	0·45	1·03	b
6 months	MZ	143	0·44	0·32	0·93	1·55
	Same-sex DZ	88	0·62	0·53	1·23	1·41
	Opp.-sex DZ	46	0·76	0·67	1·39	b
9 months	MZ	140	0·45	0·30	0·93	1·45
	Same-sex DZ	92	0·76	0·64	1·44	2·00
	Opp.-sex DZ	45	0·88	0·83	1·58	b
12 months	MZ	146	0·44	0·33	0·90	1·87
	Same-sex DZ	96	0·82	0·70	1·72	2·18
	Opp.-sex DZ	46	0·90	0·81	1·75	b
1·5 years	MZ	140	0·44	0·30	0·90	1·61
	Same-sex DZ	91	0·98	0·79	1·92	2·97
	Opp.-sex DZ	44	0·89	0·90	1·67	b
2 years	MZ	143	0·46	0·33	0·90	1·49
	Same-sex DZ	95	1·06	0·90	1·93	3·02
	Opp.-sex DZ	42	0·99	0·90	1·67	b
3 years	MZ	137	0·50	0·39	0·90	1·92
	Same-sex DZ	96	1·25	1·01	2·26	3·53
	Opp.-sex DZ	42	1·00	0·87	1·89	b
4 years	MZ	116	0·62	0·45	1·24	2·37
	Same-sex DZ	80	1·61	1·35	3·05	4·52
	Opp.-sex DZ	34	1·36	0·79	b	b

a Based on all opposite-sex pairs born 1968–70.

b Insufficient pairs for reliable estimate.

Table 4. Weight differences (kg) within twin pairs from birth to four years.

Age	Type of pairs	No. of pairs	Mean	Centiles 50	90	97
Birth	MZ	88	1·8	1·3	5·1	5·7
	Same-sex DZ	44	1·6	1·3	3·8	5·1
	Opp.-sex DZ[a]	88	2·2	1·3	5·1	7·6
3 months	MZ	127	1·4	1·0	2·9	4·2
	Same-sex DZ	85	1·6	1·4	3·2	4·0
	Opp.-sex DZ	34	2·2	1·8	4·5	b
6 months	MZ	143	1·3	1·0	2·8	3·8
	Same-sex DZ	89	1·9	1·8	3·6	4·5
	Opp.-sex DZ	46	2·0	1·5	5·0	b
9 months	MZ	140	1·3	0·9	2·8	3·5
	Same-sex DZ	92	1·8	1·4	3·8	5·4
	Opp.-sex DZ	45	2·3	2·2	4·3	b
12 months	MZ	146	1·3	1·0	2·7	3·5
	Same-sex DZ	95	1·8	1·5	3·7	5·4
	Opp.-sex DZ	46	2·1	2·0	3·7	b
1·5 years	MZ	141	1·1	0·9	2·2	3·9
	Same-sex DZ	91	2·2	1·9	4·4	5·2
	Opp.-sex DZ	44	2·2	2·0	4·3	b
2 years	MZ	143	1·1	0·9	2·5	4·0
	Same-sex DZ	94	2·4	2·1	4·9	6·2
	Opp.-sex DZ	42	2·4	2·0	4·7	b
3 years	MZ	136	1·1	0·9	2·3	3·7
	Same-sex DZ	93	2·9	2·6	5·1	7·8
	Opp.-sex DZ	42	2·5	2·0	5·1	b
4 years	MZ	115	1·1	0·9	2·3	3·7
	Same-sex DZ	79	3·2	2·7	5·8	7·5
	Opp.-sex DZ	34	2·6	1·8	b	b

a Based on all opposite-sex pairs born 1968–70.

b Insufficient pairs for reliable estimate.

Table 5. Height differences (cm) within twin pairs from birth to four years.

WEIGHT Birth Differences	Zyg.	3 Months	6	9	12	1·5 Years	2	3	4
Above median	MZ	97	87	90	89	79	85	80	84
	Same-sex DZ	88	81	80	78	75	74	71	68
Below median	MZ	80	74	63	65	73	66	57	55
	Same-sex DZ	50	57	67	63	55	59	51	70
HEIGHT 3-month Differences									
Above median	MZ		80	89	79	71	78	74	71
	Same-sex DZ		86	88	82	80	84	82	86
Below median	MZ		60	46	57	60	57	45	50
	Same-sex DZ		68	69	55	60	65	59	60

Note. Height differences based on measures at 3 months due to incomplete birth length data.

Table 6. Percentage of pairs in which larger twin at birth (weight) or three months (height) remained larger at subsequent ages.

were counted at each age in which the heavier twin maintained his advantage, and this was expressed in percentage form. Since it seemed that the magnitude of the birth-weight difference might influence the relative size of the twins at later ages, the sample was divided into pairs with birth-weight differences greater than the median, versus pairs with smaller differences. The results are presented in table 6.

Among MZ pairs with large differences ($>0 \cdot 24$ kg), the heavier twin maintained his weight advantage in about 90 per cent of the cases during the first year, and in 80–85 per cent of the cases during the subsequent three years. For small-difference MZ pairs, however, the percentage was much lower and by 4 years of age, the chances were hardly better than 50–50 that the heavier twin at birth would still outweigh his co-twin.

The trends were similar for DZ twins, especially among large-difference DZ pairs, although the percentage of heavier twins maintaining their advantage was consistently lower than the corresponding MZ percentage. In the case of small-difference DZ pairs, the percentage fluctuated so markedly from age to age as to suggest differential spurts of growth that produced frequent reversals within the pair. Clearly the heavier twin did not enjoy a consistent advantage over age; and in general, the ordering of weight within DZ pairs seemed to be less influenced by relative birth size than for MZ pairs.

The same analysis was made for height, but with the differences being based on the measures at 3 months since the birth length data were incomplete. The results are shown in table 6.

Among MZ pairs with height differences greater than the median (1·0 cm), the initially larger twin held his height advantage in about 80 per cent of the cases during the first year, and in more than 70 per cent of the cases during the following years. Where there were only small height differences within the pair, however, the initially larger MZ twin held practically no systematic height advantage over his co-twin at any age—the figure never exceeded 60 per cent and on occasion dropped as low as 45 per cent. The height differences in these MZ pairs were very small to begin with (<1·0 cm), and within these narrow limits, the changes in relative height seemed to be randomly determined.

Turning to DZ pairs with height differences greater than the median, the larger twin consistently maintained a height advantage, with the percentages remaining in the mid-80's throughout the 4-year period. Even among DZ pairs with small initial differences, the figure stabilized at 60 per cent. These figures exceed the corresponding MZ percentages, and of course the size differences within DZ pairs were considerably larger.

4. Discussion

These data show that while the differences in birth size were generally comparable for MZ twins and DZ twins, at the extreme the largest differences were found among MZ pairs. Presumably this reflects the cases in which placental anastomosis had caused an unequal distribution of nourishment among twins sharing a monochorionic placenta.

For DZ twins, the common factors of maternal source and gestational age increased their concordance at birth, but these influences waned in the postnatal months and the within-pair correlations progressively receded to intermediate values consonant with the genetic relationship. It is particularly interesting to note that DZ twins progressively diverged in size even though raised in a common family environment, with presumably similar diet and familial attitudes about eating.

When this is appraised in light of the opposite trend for MZ pairs, where concordance systematically increased and the twins converged on a common value, it seems evident that the genotype's influence on growth was both potent and progressive. Its influence was masked initially by prenatal effects, but each successive age permitted the influence of the genotype to be more fully revealed. Its contribution ultimately was more definitive for height than weight, and undoubtedly height is better buffered against nutritional deficit or variation in eating habits.

These data of course do not deny the significance of nutrition for growth. They simply make it evident that in a large, representative sample of twins, the initially powerful prenatal influences are gradually neutralized, and postnatal growth moves insistently in a direction that is determined by the genotype. It is quite possible that certain genotypes are more susceptible than others to growth potentiation or suppression as a function of nutritional adequacy. But given the broad range of diets and eating habits represented among these twins, the growth trends within each pair ultimately overlapped in proportion to the number of genes shared in common.

Prenatal influences and genetic growth patterns also affect the consistency with which size differences are maintained in each pair. Differences in birth weight reflect to a maximum degree the influence of the prenatal environment, and as noted above, such influence may accentuate differences in certain MZ pairs, or it may compress the differences in many DZ pairs.

As twins progressively escape these influences following birth, the genotype exerts a larger differential effect within the pair, and it may (*a*) amplify already existing differences, (*b*) produce a differentiation of growth trends which had been compressed prior to birth, or (*c*) compensate for prenatal inequalities and thereby reduce the differences in birth size.

For MZ twins with large differences, the common genotype would be expected to push the lighter twin toward the heavier twin, but this compensatory push would not typically carry him beyond the heavier twin. Accordingly, the heavier twin at birth would be likely to remain the heavier twin at later ages, even though his co-twin had gained enough to offset much of the initial deficit.

For DZ twins, the genotypic growth trends begin to differentiate in the early postnatal months, and in some pairs the initially smaller twin may have greater potential for growth. Consequently he would overtake his co-twin at a later age; and for the DZ sample as a whole, there would be proportionally fewer pairs in which the heavier twin at birth consistently held his weight advantage at later ages.

The weight percentages in table 6 fit this interpretation, and it would be expected to hold for the height percentages as well. However, in the present sample the twins were separated into larger and smaller on the basis of height at 3 months, since the birth length data were incomplete. Thus for DZ twins the separate genotypes had already had an opportunity to differentiate the growth trends and produce a more definite ordering of heights within the pair. The larger DZ twin at 3 months held a height advantage that was more firmly rooted in the genotype than was true at birth, and as a consequence he had a higher probability of remaining the larger twin at later ages. The figures in table 6 show that in more than 80 per cent of the pairs he held his advantage consistently across ages.

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Zusammenfassung. Körperhöhe und Gewicht wurden bei 636 Zwillingen mit wiederholten Messungen von der Geburt bis 4 jahre untersucht. EZ waren im Geburtsgewicht weniger konkordant als ZZ, hauptsächlich aufgrund weniger EZ mit sehr grossen Unterschieden. Im Alter von einem Jahr jedoch waren die EZ im Gewicht stärker konkordant geworden ($r=0{,}87$), während die ZZ sich stärker voneinander entfernten ($r=0{,}55$). Bei der Geburtslänge betrug die Korrelation der EZ 0,58 und der ZZ 0,82, aber bei 2 Jahren erreichte sie bei den EZ 0,89 und fiel bei den ZZ auf 0,58 ab. Die tatsächlichen Grössendifferenzen zwischen den

Paarlingen zeigten einen entsprechenden Verlauf—bei EZ wurden Unterschiede nach der Geburt kleiner, bei ZZ jedoch grösser. Die Ergebnisse werden diskutiert vor dem Hintergrund (a) der pränatalen Einflüsse, die die Geburtsgrössen der EZ- und ZZ-Paarlinge differenzieren können und (b) der schnellen Annäherung jedes Zwillings an seine genetische Wachstumskurve.

Résumé. La taille et le poids ont été mesurés périodiquement de la naissance à 4 ans dans un échantillon de 636 jumeaux. Les jumeaux MZ ont été trouvés moins concordants en poids à la naissance que les jumeaux DZ, ce qui est dû principalement à quelques paires de MZ qui présentaient des différences très grandes. A l'âge d'un an cependant, les jumeaux MZ étaient devenus progressivement plus concordants en poids (R_{mz}=0,87) tandis que les jumeaux DZ divergaient davantage (R_{dz}=0,55). Le tableau était encore plus prononcé pour la taille; à la naissance, la corrélation entre MZ était de 0,58 tandis que la corrélation entre DZ était de 0,82. Mais à 2 ans, la corrélation entre MZ atteignait 0,89 tandis que la corrélation entre MZ régressait à 0,58. Les différences de dimensions au sein des paires suivaient une évolution parallèle: les différences entre jumeaux MZ diminuaient après la naissance, tandis que celles entre jumeaux DZ croissaient. Les résultats sont discutés en termes (*a*) d'influences prénatales affectant différemment le format à la naissance au sein des paires MZ et DZ, et (*b*) de convergence rapide de chaque jumeau vers sa courbe de croissance génétique.