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Physical and Motor Fitness in Twins

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Abstract Thirty pairs of monozygotic (MZ) and 20 pairs of dizygotic (DZ) twins, of both sexes, were studied to estimate the role of genetic and environmental factors determining fitness measurements comprising vital capacity (VC), vertical jump, flexibility, agility, and PFI score. Intra-pair variances for VC, vertical jump, and heart rate were significantly smaller ($p<0.05$–0.01) in MZ than in DZ twins, where values for flexibility, agility, and PFI were insignificant. Intra-pair correlations for VC, vertical jump, and heart rate were higher ($p<0.01$) in MZ than in DZ twins where the opposite was found in the case of flexibility and agility. The correlation value for PFI was higher in both MZ and DZ twins. Following adjustment for physical characteristics including age, weight, and height, none of the results of all the residual fitness measurements were similar to the unadjusted values. Both unadjusted and residual variables with smaller intra-pair variances showed higher heritability estimates. These results suggest that VC, vertical jump, and heart rate are influenced more by genetic factors than environmental factors where the inverse is true of flexibility, agility, and PFI. Thus, the genetic and environmental influence of all the fitness measurements, except VC, more or less depend upon physical characteristics in this study.

Key words: fitness measurements, physical characteristics, twins, genetics, environments.

The question is frequently raised concerning the genetic contribution to exercise performance. Several investigators have reported that human variation in physical and motor fitness is closely associated with age, sex, weight, height, occupational habits, and nutritional and socio-economic factors, etc. However, the

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number of genetic and environmental studies on fitness measurements is possibly insufficient in different parts of the world, especially in India. Venerando and Milani-comparetti [1] stated that intra-pair concordances for vital capacity and muscular strength were higher in MZ twins than DZ twins. Klissouras [2] found that intra-pair variance for physical capacity in terms of maximal oxygen uptake was smaller in MZ than in DZ twins. Engstrom and Fischbein [3] observed that physical work capacity was a more environmentally influenced variable than either vital capacity or muscular strength. Sensitivity of maximal aerobic power to endurance training is largely genotype-dependent [4]. Environmental factors such as injury or athletic activity can alter flexibility while the underlying morphology remains constant in identical twins [5]. Fagard *et al.* [6] stated that at rest, heart rate was found to be a genetically determined variable.

The purpose of the present study was, therefore, to estimate the degree of genetic and environmental influence on physical and motor fitness measurements independent of physical characteristics.

SUBJECTS AND METHODS

Fifty-four healthy non-smoking twin pairs (mean age = 15 years) were investigated in the present study. The subjects were from middle class families in semiurban and rural areas. Twins were classified as monozygotic (MZ = 30 pairs) and dizygotic (DZ = 24 pairs) twins of both sexes according to a special schedule of earlier investigators [7, 8]. Their zygosity was established by blood type (ABO, Rh, and MN), fingerprints, physical appearances, and parental history. Twins were judged as MZ when all the blood markers matched, more than seven fingerprints were similar and physical appearances such as eyebrows, nose, ear lobe attachments, frontal hair line, dental nature, and hair whorls on the crown of the head were highly concordant. A marked similarity in physical features gives a 93% probability of MZ and adding serological and dermatographic analyses, accuracy of 98% is obtained [8]. Each twin answered by questionnaire [9] and was examined by a pathologist of Tamluk Sub-divisional Hospital.

Vital capacity was measured by two 9-*l* closed-circuit type expirographs using a standard spirometric technique [10]. At least three satisfactory trials were given for each measurement, with at least 3–5 min rest between trials. The test was performed in the standing position and a noseclip was used. Lung volume was expressed in body temperature and pressure saturated with vapor (BTPS). Vertical Jump, flexibility, and agility were measured by the Sargent Vertical Jump Test [11], the Sit and Reach Test [12] and the Shuttle Run Test [13], respectively. Cardiovascular fitness in terms of PFI score was measured by the Harvard Step Test [14] adjusting the stool height according to the subjects' height [15]. The PFI score was calculated by the following formula:

$$\frac{\text{Duration of exercise in seconds} \times 100}{2 \times (\text{Sum of 3 recovery pulses from 1–1.5, 2–2.5, and 3–3.5 min})}.$$

Anthropometric measurements like weight, standing height, sitting height, and knee height were measured without footwear and with light clothing. Body surface area (BSA) was calculated using the formula of DuBois and DuBois [16]. The whole experiment was performed in an uncontrolled laboratory with a temperature of 25–31°C.

To determine the degree of intra-pair similarity in fitness measurements of twin pairs and to compare intra-pair similarity in between MZ and DZ twins, the F test was performed using the formula:

$$F = \delta^2\text{WDZ}/\delta^2\text{WMZ}. \quad (1)$$

Where, δ^2WDZ and δ^2WMZ are the intra-pair variances for DZ and MZ, respectively. For further study of the concordance for MZ twin pairs in comparison with DZ twin pairs, the intra-pair correlation for fitness measurements were estimated. The formula used is

$$r = \frac{V_{bp} - V_{wp}}{V_{bp} + V_{wp}}, \quad (2)$$

where, r = intra-pair correlation, V_{bp} = between pair variance, and V_{wp} = intra-pair variance. When the calculated F was significantly larger than the tabulated F ($p < 0.05$), genetic variance was thought to be present [17].

Predicted values of physical and motor fitness measurements were obtained from this population using regression equations that related fitness measurements to significant physical characteristics. Regression equations were calculated separately for MZ and DZ twins to allow for differences in the covariance structure in each of these groups. Residual fitness measurements were determined by subtracting the predicted values from the observed values. Thus, the F test was performed on residual values like observed values.

Heritability estimates of different fitness measurements were calculated using unadjusted values and residual values according to the formula

$$H^1 = \frac{\delta^2\text{WDZ} - \delta^2\text{WMZ}}{\delta^2\text{WDZ}}, \quad (3)$$

where, H^1 = statistical symbol for Holzinger's heritability estimate, δ^2WDZ = intra-pair variance for DZ and δ^2WMZ = intra-pair variance for MZ. In Holzinger's formula several assumptions are made, of which environmental and genetic are additive.

RESULTS

Table 1 describes the characteristics of twins, and measurements are not

Table 1. Different characteristics of twins.

Measurements	Twin subjects MZ	Twin subjects DZ	$N=n_1/n_2$
Age (years)	16.40±5.30	14.47±3.21	60/48
Standing height (cm)	147.55±16.40	142.41±11.09	60/48
Sitting height (cm)	75.30±7.52	73.36±9.00	60/48
Knee height (cm)	46.31±4.72	44.73±3.26	60/48
Weight (kg)	36.50±10.67	33.43±8.88	60/48
Body surface area (m^2)	1.23±0.25	1.15±0.18	60/48
Vital capacity (l)	2.45±0.84	2.20±0.62	60/44
Vertical jump (inches)	9.65±2.20	9.56±2.43	60/48
Flexibility (inches)	19.72±1.95	19.05±3.52	60/48
Agility (s)	11.29±0.82	11.39±0.95	54/48
Heart rate (beats·min^{-1})	86.46±15.74	87.64±15.89	56/48
PFI	82.49±24.75	68.62±24.37	56/48

$df=n_1+n_2-2$; n_1=MZ and n_2=DZ. Results are means±standard deviation.

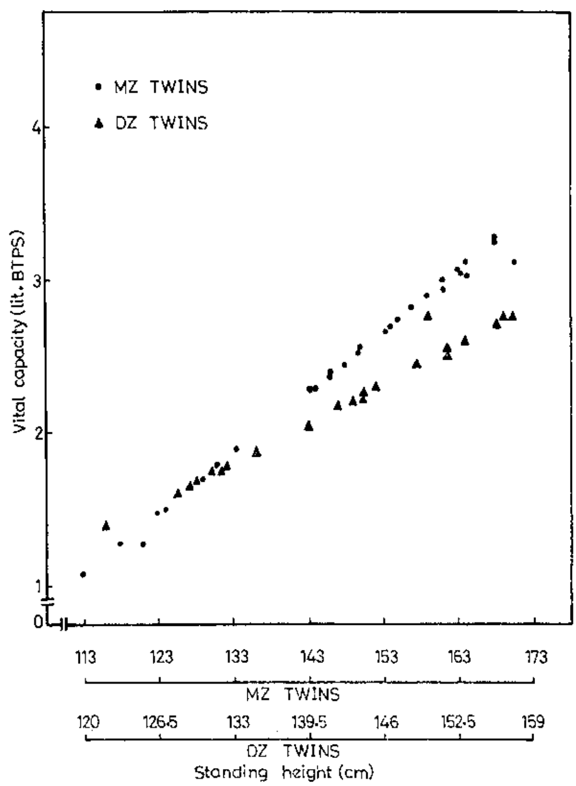

Fig. 1. Relationship of vital capacity to standing height in MZ twins and DZ twins.

Table 2. Intra-pair variance and intra-pair correlation of different fitness measurements.

Measurements	Intra-pair variance			Intra-pair correlation		N	
	δ^2WDZ	δ^2WMZ	F values	MZ	DZ	MZ	DZ
Vital capacity (l)	0.17	0.02	8.50**	0.94**	0.17 NS	30	22
Vertical jump (inches)	3.42	0.98	3.48**	0.60**	−0.14 NS	30	24
Flexibility (inches)	1.94	1.59	1.22 NS	0.22 NS	0.68**	30	24
Agility (s)	—	—	—	—	0.46**	27	24
Heart rate (beats·min^{-1})	87.89	33.39	2.63**	0.71**	0.29 NS	28	24
PFI	166.45	108.73	1.53 NS	0.63**	0.42*	28	24

NS = not significant. *$p<0.05$, **$p<0.01$.

Table 3. Inter-pair variance and intra-pair correlation of different fitness measurements in boy and girl twins.

Measurements	Inter-pair variance ratio		Inter-pair correlation			
	Boy	Girl	Boy		Girl	
			MZ	DZ	MZ	DZ
Vital capacity (l)	0.66 NS	0.40 NS	0.83**	0.82**	0.41 NS	0.80*
Vertical jump (inches)	14.75**	0.83 NS	0.96**	0.57*	0.44 NS	0.43 NS
Flexibility (inches)	0.18 NS	0.53 NS	0.05 NS	0.86**	0.72**	0.25 NS
Agility (s)	0.06 NS	0.66 NS	0.03 NS	0.95**	0.80**	0.55 NS
Heart rate (beats·min^{-1})	2.02 NS	1.30 NS	0.66**	0.33 NS	0.76**	0.76*
PFI	0.31 NS	0.32 NS	0.57**	0.69**	0.53**	0.87**

NS = not significant. *$p<0.05$, **$p<0.01$.

Table 4. Correlation coefficient of physical fitness measures and anthropometric parameters.

Physical fitness measures	Age (year)		Weight (kg)		Standing height (cm)	
	MZ	DZ	MZ	DZ	MZ	DZ
Vital capacity (*l*)	0.73^{*5}	0.47^{*4}	0.91^{*5}	0.77^{*5}	0.93^{*5}	0.73^{*5}
Vertical jump (inches)	0.51^{*5}	0.17 NS	0.76^{*5}	0.51^{*5}	0.81^{*5}	0.57^{*5}
Flexibility (inches)	0.42^{*5}	0.20 NS	0.54^{*5}	0.41^{*4}	0.47^{*5}	0.30^{*2}
Agility (s)	0.87^{*5}	−0.06 NS	−0.12 NS	−0.34^{*3}	0.05 NS	−0.42^{*4}
Heart rate (beats·min^{-1})	0.48^{*5}	0.06 NS	−0.49^{*5}	−0.01 NS	−0.48^{*5}	−0.13 NS
PFI	0.25^{*1}	−0.42^{*4}	0.23^{*1}	−0.33^{*2}	0.01 NS	−0.14 NS

Physical fitness measures	Sitting height (cm)		BSA (m^2)	
	MZ	DZ	MZ	DZ
Vital capacity (*l*)	0.92^{*5}	0.71^{*5}	0.87^{*5}	0.78^{*5}
Vertical jump (inches)	0.84^{*5}	0.55^{*5}	0.69^{*5}	0.46^{*4}
Flexibility (inches)	0.52^{*5}	0.36^{*3}	0.36^{*4}	0.26^{*1}
Agility (s)	−0.43^{*4}	−0.40^{*4}	−0.37^{*4}	−0.69^{*5}
Heart rate (beats·min^{-1})	−0.54^{*5}	−0.07 NS	−0.49^{*4}	−0.19 NS
PFI	0.34^{*3}	−0.15 NS	0.27^{*2}	−0.35^{*3}

NS = not significant. $^{*1}p<0.1$, $^{*2}p<0.05$, $^{*3}p<0.02$, $^{*4}p<0.01$, $^{*5}p<0.001$.

similar between MZ and DZ twins. The study revealed that MZ and DZ twins were quite comparable in terms of mean age, standing height, knee height, vital capacity, flexibility, agility, and PFI.

Table 2 shows the results of fitness measurements. Analysis of variance disclosed that intra-pair variances of vital capacity, vertical jump, and heart rate were significantly smaller ($p < 0.05$–0.01) in MZ in comparison with DZ twins and the values of flexibility, agility, and PFI score are not significant. Intra-pair correlations show higher concordance ($p < 0.01$) in all measurements for MZ twins with the exceptions of flexibility and agility. On the other hand, the correlation values for flexibility, agility, and PFI, in the case of the DZ twins, are significantly higher ($p < 0.05$–0.01) and the other values are insignificant.

Table 3 revealed that none of the intra-pair variance ratios for all of the fitness measurements were significantly different between MZ and DZ twins of both boy and girl twin populations, with the exception of vertical jump in the boy twin pairs. The results also disclosed that, except for PFI, the intra-pair correlation values of all the measurements in both same sex pairs were not consistent with the opposite-sex pairs.

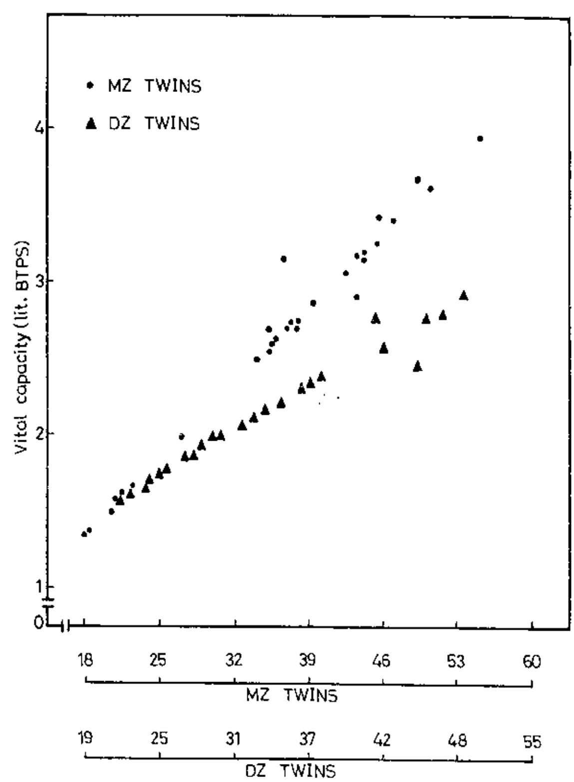

Fig. 2. Relationship of vital capacity to body weight in MZ twins and DZ twins.

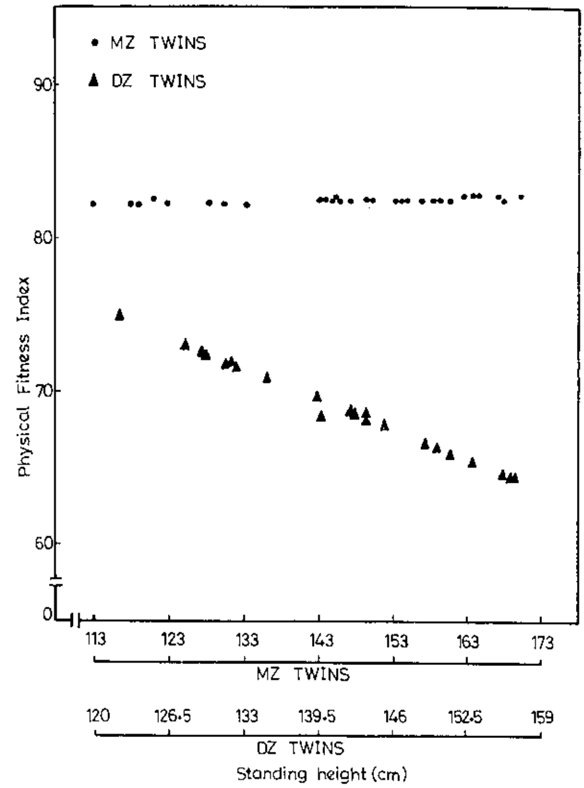

Fig. 3. Relationship of physical fitness index to standing height in MZ twins and DZ twins.

The product moment correlations based on the physical characteristics and fitness measurements in both MZ and DZ twins are given in Table 4 and Figs. 1–4. In the MZ twin population, vital capacity, vertical jump, and flexibility showed a significant positive correlation ($p<0.05$–0.001) and heart rate showed a significant negative correlation ($p<0.001$) with all the physical characteristics with the exception of age versus heart rate. Agility showed a significant positive correlation ($p<0.001$) with age, insignificant correlations with weight and standing height and a significant negative correlation ($p<0.01$–0.001) with sitting height and BSA. PFI indicated a significant and positive correlation with all the physical characteristics except standing height. In the DZ twin population, the correlation values for vital capacity, vertical jump, and flexibility are similar between MZ twins with the exception of the correlations for age versus vertical jump and flexibility. Agility and PFI showed significant and negative correlations with all the physical characteristics except age with agility, which was insignificant. Insignificant correlations were found between heart rate and all the physical characteristics.

The results of residual scores of concomitant variables are summarized in

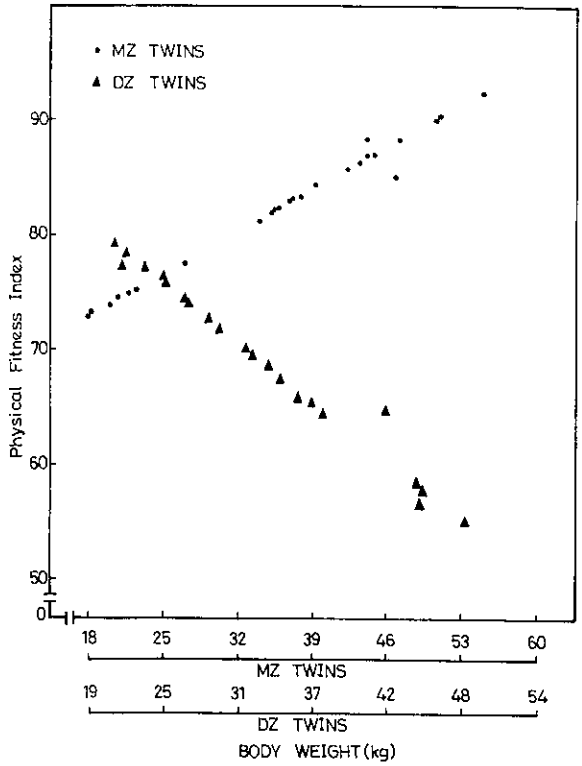

Fig. 4. Relationship of physical fitness index to body weight in MZ twins and DZ twins.

Tables 5 and 6. Our data revealed that all the residual scores of vital capacity and vertical jump were significantly smaller ($p<0.01$) in MZ twins than in DZ twins after adjustment for all the physical characteristics except standing height for vertical jump. Age- and weight-adjusted residual flexibilities, weight-, standing height- and sitting height-adjusted residual scores of agility, sitting height- and BSA-adjusted residual scores for heart rate, and age-, weight-, and standing height-adjusted residual PFI scores were significantly lower ($p<0.05$–0.01) in MZ twins in comparison with DZ twins where, in contrast, intra-pair variances of other respective residual scores of concomitant variables were insignificant. Table 5 shows that the intra-pair correlation values for all the residual fitness measurements in MZ twins were significantly higher ($p<0.05$–0.01) with the exception of standing height-adjusted residual vertical jump. On the other hand, all the correlation values for residual flexibility, agility, and PFI in DZ twins were significantly higher ($p<0.05$–0.01) following adjustment for all the physical characteristics except BSA-adjusted residual PFI score. Since then, all the correlation values for residual vital capacity and vertical jump were insignificant; conversely, all the correlation

Table 5. Intra-pair variance of residual fitness measurements following adjustment for physical characteristics.

Measurements	Age (years)	Weight (kg)	Standing height (cm)	Sitting height (cm)	BSA (m^2)	N	
						MZ	DZ
Vital capacity (*l*)	4.66**	3.50**	4.25**	2.83**	4.00**	30	22
Vertical jump (inches)	4.02**	7.05**	1.29 NS	6.89**	3.21**	30	24
Flexibility (inches)	2.00*	2.00*	1.84 NS	1.85 NS	1.08 NS	30	24
Agility (s)	1.00 NS	2.50*	3.57**	3.37**	1.75 NS	27	24
Heart rate (beats·min^{-1})	1.38 NS	1.36 NS	0.76 NS	2.24*	2.33*	28	24
PFI	5.04**	2.01*	2.58**	1.48 NS	1.26 NS	28	24

NS=not significant. *$p<0.05$, **$p<0.01$.

Table 6. Intra-pair correlation of residual fitness measurements following adjustment for physical characteristics.

Measurements	Age (years)		Weight (kg)		Standing height (cm)		Sitting height (cm)		BSA (m^2)		N	
	MZ	DZ	MZ	DZ	MZ	DZ	MZ	DZ	MZ	DZ	MZ	DZ
Vital capacity (*l*)	0.91**	0.26 NS	0.88**	0.26 NS	0.88**	0.15 NS	0.83**	0.15 NS	0.86**	0.11 NS	30	22
Vertical jump (inches)	0.85**	0.21 NS	0.84**	0.08 NS	0.08 NS	0.02 NS	0.84**	0.09 NS	0.73**	0.23 NS	30	24
Flexibility (inches)	0.73**	0.60**	0.75**	0.64**	0.74**	0.63**	0.74**	0.64**	0.46*	0.66**	30	24
Agility (s)	0.77**	0.60**	0.68**	0.52**	0.58**	0.47**	0.76**	0.47**	0.66**	0.62**	27	24
Heart rate (beats·min^{-1})	0.70**	0.15 NS	0.71**	0.06 NS	0.72**	0.72**	0.72**	0.39*	0.60**	0.008 NS	28	24
PFI	0.77**	0.42*	0.43**	0.33*	0.54**	0.42**	0.64**	0.35*	0.47**	0.28 NS	28	24

NS=not significant. *$p<0.05$, **$p<0.01$.

Table 7. Heritability estimates (percentage) of fitness measurements.

Measurements	Before adjustment	Following adjustment				
		Age (years)	Weight (kg)	Standing height (cm)	Sitting height (cm)	BSA (m^2)
Vital capacity (*l*)	88	78	71	76	64	75
Vertical jump (inches)	71	75	85	22	85	68
Flexibility (inches)	18	50	50	45	46	07
Agility (s)	100	100	60	72	70	42
Heart rate (beats·min^{-1})	62	27	26	—	55	57
PFI	34	80	50	61	32	20

values, in the case of residual heart rate, were significantly higher ($p < 0.05$–0.01) except for age, weight, and BSA-adjusted values.

A quantitative statement of heritability estimates of fitness measurements are given in Table 7. The results indicate that vital capacity, vertical jump, agility, and heart rate were highly (62–100%) heritable components in comparison with flexibility and PFI before adjustment for physical charateristics. Since, after adjustment for physical characteristics comprising age, weight, standing height, sitting height, and BSA, all the residual fitness measurements were heritable components with the exception of standing height-adjusted heart rate and heritability estimates ranged from 7–100% which were more or less comparable to unadjusted variables. It is mentioned that the variables with higher F values showed a high level of heritability estimates.

DISCUSSION

Classical twin studies may overestimate the relative contribution of genetics and environment to the variability of physiologic characteristics [17]. By comparing variances between MZ (common genetic and environmental factors) and DZ (common environmental and different genetic factors), whether the terms of interest are governed predominantly by genetics can be determined. For this purpose, young twins are most suitable because they share common environments [8].

As revealed in the above results, none of the physical and motor fitness measurements were concordant between MZ and DZ twins. This might be due to differences in physical characteristics between the two groups of subjects. Several studies have shown that fitness measurements depend on sex, age, weight, height, body size, occupational habits [3, 18–22] etc.

The present investigation has disclosed that intra-pair variances for vital capacity, vertical jump, and heart rate are significantly smaller in MZ twins than in DZ twins, indicating that these measurements are influenced mainly by genetic factors and that environmental factors play a smaller role. Conversely, flexibility, agility, and PFI score are not strongly influenced by genetic factors. Very similar attempts were made, for vital capacity, by Venerando and Milani-Comparetti [1] and Engstrom and Fischbein [3], while Serebrovskaya *et al.* [23] reported that vital capacity is equally dependent on heredity and environment. This discordance might be due to occupational habits [24], stature [18, 25], and physical exercise [3, 22] in the present study. Similar observations regarding muscular strength were made by Venerando and Milani-Comparetti [1] and it was different from the study of Engstrom and Fischbein [3]. This is possibly due to differences in physical exercise [3] and body stature [18, 25, 26]. A number of investigators, such as Havlik *et al.* [27], Fagard *et al.* [6], Hanson *et al.* [28], found that genetics is an important determinant of normal heart rate. This is consistent with our result for the same variable.

The study, environmental determination of flexibility, was obtained by the present study. It was consistent with the study of Palamarchuk [4] who suggested that environmental factors such as injury or athletic activity could alter flexibility while the underlying morphology remained constant in identical twins. For bodily agility, the present study was quite similar to the study of Gettman *et al.* [29], where a study by Liebing [30] reported slight differences. This discordance might be due to age, height [5], and occupational habits. We previously reported [21] that the major influence of age on the different fitness measurements like vertical jump, flexibility, and agility in boys became apparent from 14–15 years of age. Gettman *et al.* [29] observed a significant effect of training on agility. Physical fitness in terms of PFI is an environmentally influenced variable in the present study. Different twin studies came to a similar conclusion for the same variable using different terms like treadmill performance [29], aerobic performance [6, 31], and physical work capacity [3, 11, 32, 33]. Klissouras [34] and Klissouras *et al.* [35], who reported contradictory findings for aerobic performance, suggested that $\dot{V}_{O_2max}$ and work capacity were almost entirely inherited variables. Age, sex, physical characteristics, exercise habits, and heredity may affect various fitness measurements [3, 21, 26] in this study.

The present findings indicate that sex and sex-related physical characteristics and habits are to be taken into account as determinants of genetic versus environmental influence of fitness measurements. Genetic and ervironmental influences on $\dot{V}_{O_2max}$ and endurance performance [36], height and weight [37], stature, and bi-illiac diameter [38] are comparable to those in the present study, especially sex-related changes in genetic and environmental determinations of fitness measurements.

Vital capacity, vertical jump, and flexibility showed a positive and significant relationship with all of the physical characteristics, with the exception of age in DZ twins, where the correlations for the other fitness measurements are not linear. These findings, in all the cases, are not systematically consistent with the studies of Chatterjee *et al.* [21], Espenschade [39], Mathews *et al.* [40], and Banerjee and

Chatterjee [41]. This difference might be due to the small number of subjects [41] and, in the case of PFI, to adjustment of stool height in accordance with the subjects' height [15]. The prediction equations for vital capacity, vertical jump flexibility, agility, and heart rate are reliable in both twin groups. SEE are noted to vary from 3 to 25% of the mean value. To investigate the genetic versus environmental determination of fitness measurements independent of anthropometric relations, residual values for those measurements are further studied using methods reported by Redline *et al.* [42] for lung function measurements.

The present findings, observed in the residual fitness measurements as compared with the unadjusted values, indicate that genetic determination of vital capacity is independent of physical parameters, where determination of vertical jump and heart rate depends more upon height and age and on weight and height, respectively, than on other characteristics. Thus, environmental determination of flexibility, agility, and PFI is possibly associated with age, weight, and standing height and sex; physical habits, puberty etc. may also be taken into account as determinants of those fitness variables [36, 43].

Regarding the heritability estimates of the fitness measurements, the present study states that genetically influenced fitness measurements, both unadjusted and residual values are highly heritable components and heritability estimates of major variables varied from 50 to 98%. Conversely, except for agility, environmentally influenced fitness measurements show a comparatively lower level of heritability estimates (7–50%). Age and sex may at least be related with the heritability estimates of all the fitness measurements of this study. The present findings are consistent with the studies of Fagard *et al.* [6], Malina and Buschang [26], Bouchard and Lortie [36], and Havlik *et al.* [27], which are possibly inconsistent with the findings of Bouchard *et al.* [44] and Klissouras *et al.* [35]. This might be due to differences in the selection of subjects, exercise protocol, statistical analysis, and environment [6, 45]. The present investigation provides information for individual physical performance and potentiality associated with genetics and environment. This also might be helpful in the determination of sports potentiality of subjects, selection of subjects for sports and athletic training programs, which may help to develop atheletic performance and sports skill.

SUMMARY

Thirty pairs of monozygotic twins aged 10–27 years and 24 pairs of dizygotic twins were investigated to estimate the genetic versus environmental influence on different fitness measurements. All of the twins were healthy, non-smokers who were raised together and who lived in rural and semiurban areas. Twins were classified as monozygotic (MZ) and dizygotic (DZ) twins, according to special schedules of Fischbein [7] and Kawakami *et al.* [8]. Vital capacity was measured using a 9-*l* closed-circuit type expirograph using a standard spirometric technique. Vertical jump, flexibility, agility, and PFI score were measured by the Sargent

Vertical Jump Test, Sit and Reach Test, Shuttle Run Test, and Harvard Step Test, respectively.

Intra-pair variances for vital capacity, vertical jump, and heart rate were significantly smaller ($p < 0.05$–0.01) in MZ than in DZ twins where as the values for flexibility, agility, and PFI were insignificant. Intra-pair correlations for vital capacity, vertical jump, and heart rate were higher ($p < 0.01$) in MZ than in DZ twins where adverse were found in the case of flexibility and agility. The correlation value for PFI was higher in both MZ and DZ twins. Thus, except for flexibility and PFI, all the measurements showed higher heritability estimates (62–100%). Vital capacity, vrtical jump, and flexibility were found to be positively and significantly correlated ($p < 0.1$–0.001) with major physical characteristics comprising age, standing height, sitting height, weight, and BSA. The results of all the residual fitness measurements, except vital capacity, were not similar to the unadjusted values. Residual values with higher intra-pair variance ratios showed higher heritability estimates.

These data indicate that vital capacity, vertical jump, and heart rate are influenced more by genetic factors than by environmental factors where the opposite is true of flexibility, agility, and PFI. Genetically influenced variables showed higher heritability estimates. Thus, genetic and environmental influence of all the fitness measurements were more or less dependant upon sex and physical characteristics in this study.

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REFERENCES

1. Venerando A and Milani-Comparetti M: Twin studies in sport and physical performance. Acta Genet Med Gemellol **19**: 80–82, 1970
2. Klissouras W: Twin studies on functional capacity. In: Proceedings of the Symposium on "Genetic and Nongenetic Components in Physiological Variability," London, England, 28 November (Mimeographed), 1975.
3. Engstrom LM and Rischbein S: Physical capacity in twins. Acta Genet Med Gemellol **33**: 565–570, 1977
4. Palamarchuk HJ: A study of the foot structure of athletic identical twins. J Am Pediatr Med Assoc **76**: 592–594, 1986
5. Montoye HJ, Frantz ME, and Kozar AJ: The values of age, height and weight in establishing standards of fitness for children. J Sports Med **12**: 174–179, 1972
6. Fagard R, Broeke CVN, Bielen E, and Amery A: Maximum oxygen uptake and cardiac size and function in twins. Am J Cardiol **60**: 1362–1367, 1987
7. Fischbein S: Intra-pair similarity in physical growth of monozygotic and of dizygotic twins during puberty. Ann Hum Biol **4**: 417–430, 1977
8. Kawakami Y, Yoshikawa T, Shida A, Asanuma Y, Yamamoto H, Koizumi M, Kamishima K, and Tsuji M: Genetic studies on respiratory functions by twin method. Jpn J Thorac Dis **18**: 339–345, 1980

9. Hrubec Z and Robinette CD: The study of human twins in medical research. N Engl J Med **310**: 435–441, 1984
10. American Thoracic Society: ATS statement Snowbird Workshop on standardization of spirometry. Am Rev Respir Dis **119**: 1979
11. Sargent DA: The physical test of a man. Am Phys Educat Rev **29**: 47–56, 1921
12. Johnson BL and Nelson JK: Practical Measurements for Evaluation in Physical Education, Surjeet Publication, New Delhi, 1982
13. AAHPER: Youth Fitness Test Manual, Youth Test Manual, American Alliance for Health Physical Education and Recreation, Washington DC, 1976
14. Brouha L: The step test: A simple method of measuring physical fitness for muscular work in young men. Res Q **14**: 31–36, 1943
15. Committee on Exercise and Physical Fitness: Is your patient fit? A simple supplementary test for evaluating patient's fitness. J Am Med Assoc **201**: 117–118, 1967
16. DuBois D and DuBois EP: Clinical calorimetry: A formula to estimate the approximate surface area if height and weight be known. Arch Intern Med **17**: 863–871, 1916
17. Christian JC, Kang KW, and Norton JJ Jr: choice of an estimate of genetic variance for twin data. Am J Hum Genet **26**: 154–161, 1974
18. Åstrand PO and Rodahl K: Textbook of Work Physiology, McGraw Hill, New York, 1970
19. Andersen KL, Rutenfranz J, Seliger V, Ilmarinen J, Berndt I, Kylian H, and Ruppel M: The growth of lung volumes affected by physical performance capacity in boys and girls during childhood and adolescence. Eur Appl Physiol **52**: 380–384, 1984
20. Cotes JE, Dabbs JM, Hall AM, Heywood C, and Lawrence KM: Sitting height, fat-free mass and body fat as reference variables in healthy British children: Comparison with stature. Ann Hum Biol **6**: 307–314, 1979
21. Chatterjee S, Mondal A, and Das N: Physical and motor fitness level of Indian school-going boys. J Sports Med Phys Fitness **33**: 268–277, 1993
22. Miller GJ, Saunders MJ, Gilsol RJC, and Ashcrofi MT: Lung function in healthy boys and girls in Jamaica in relation to ethnic composition, test exercise performance and habitual physical activity. Thorax **32**: 486–497, 1977
23. Serebrovskaya, TV and Lipskii PYu: Genetic control levels of functional indices for the human cardiorespiratory system. Fiziol Zh (Kiev) **28**: 267–273, 1982
24. Krishnan BT and Vareed C: A function study of vital capacity of South Indians. Indian J Med Res **21**: 131
25. McMiken DF: Maximum aerobic power and physical dimensions of children. Ann Hum Biol **3**: 141–147, 1976
26. Malina RM and Buschang PH: Growth, strength and motor performance of Zapotec children, Baxaca, Mexico. Hum Biol **57**: 163–182, 1985
27. Havlik RJ, Robert J, Carrison RF, and Feinleiz M: Variability of heart rate, P-R, QRS and QT durations in twins. J Electrocardiol **113**: 45–48, 1980
28. Hanson BN, Bouchard T, Heston L, Lykken D, Segal N, and Rich S: Genetic factors in the electrocardiogram and heart rate of twins reared apart and together. Am J Cardiol **63**: 606–609, 1989
29. Cettman LR, Storer TW, and Ward RD: Fitness changes in professional football players during preseason conditioning. Phys Sports Med **15**: 92–96, 99–101, 1987
30. Liebing M: Comparison of motor variables in twins of same sex. Med Sports (Berl) **27**:

109–112, 1987
31. Demmersman RE, Schaefer DC, Miller WW, and Nance WE: Adaptation to maximal effort: Genetic vs. environment: A case history. Acta Genet Med Gemellol **33**: 565–570, 1984
32. Ekblom B: Effect of physical training in adolescent boys. J Appl Physiol **27**: 350–355, 1969
33. Erikson BO: Physical training, oxygen supply and muscle metabolism in 11–13 years old boys. Acta Physiol Scand (Suppl) **384**: 1972
34. Klissouras V: Heritability of adaptive variation. J Appl Physiol **31**: 338–344, 1971
35. Klissouras V, Pirnay F, and Petit JM: Adaptation to maximal effort: Genetics of age. J Appl Physiol **35**: 288–293, 1973
36. Bouchard C and Lortie G: Heredity and endurance performance. Sports Med **1**: 38–64, 1984
37. Fischbein S: Intra-pair similarity in physical growth of opposite-sex twin pairs during puberty. Ann Hum Biol **10**: 135–145, 1983
38. Kramer AA, Green LJ, Croghan IT, Buck GM, and Ferer R: Bivariate path analysis of twin children for stature and biiliac diameter: Estimation of genetic variation and co-variation. Hum Biol **58**: 517–525, 1986
39. Espenschade A: Restudy of relationship between physical performances of school children and age, height and weight. Res Q **34**: 144–153, 1963
40. Mathews DX, Shaw V, and Wood JB: Hip flexibility of elementary school boys as related to body segments. Res Q **30**: 297–302, 1959
41. Banerjee PK and Dhatterjee S: Harvard Step Test as a measure of physical fitness in adolescent boys. Indian J Med Res **79**: 413–417, 1983
42. Redline S, Tishler RV, Posner B, Lewitter FI, Vandenburgh M, Weiss ST, and Speizer FE: Genotype and phenotypic similarities in pulmonary function among family members of adult monozygotic and dizygotic twins. Am J Epidemiol **129**: 827–836, 1989
43. Keithley RB: The relationship between physiological age and motor and physical development. quoted from Clarke HH and Harrison JCE: Differences in physical and motor traits between boys of advanced, normal and retarded maturity. Res Q **33**: 13–25, 1962
44. Bouchard C, Lesage R, Lortie G, Simoneau J, Hamel P, Boulay MR, Perusse L, Theriault G, and Leblanc C: Aerobic performance in brothers, dizygotic and monozygotic twins. Med Sci Sports Exercise **18**: 639–646, 1986
45. Kagmimori S, Robson JM, Heywood C, and Cotes JE: Genetic and environmental determinants of the cardiorespiratory response to submaximal exercise: A 6-year follow up study of twins. Ann Hum Biol **11**: 29–38, 1984