Fatness and fat patterning among athletes at the Montreal Olympic Games, 1976

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ABSTRACT

MALINA, ROBERT M., WILLIAM H. MUELLER, CLAUDE BOUCHARD, RICHARD F. SHOUP, and GEORGES LARIVIERE. Fatness and fat patterning among athletes at the Montreal Olympic Games, 1976. Med. Sci. Sports Exercise, Vol. 14, No. 6, pp. 445-452, 1982. Six skinfold measurements for male and female athletes (N = 456) at the 1976 Montreal Olympic Games were analyzed to identify principal components of fatness and anatomical distribution of fat, i.e., fat patterning. As in non-athletes, two principal components were evident among the athletes. All skinfolds were correlated positively with the first component, which was termed fatness, while extremities fat measurements were correlated positively and trunk measurements were correlated negatively with the second principal component, which was termed an extremity/trunk ratio component. The two principal components accounted for about 85% of the variance. The first component was related to control variables in order of descending contribution to its variance as follows: sex (21-31%), sport (19%), ethnicity (3%), and age (1-3%). Likewise, the second component (extremity/trunk ratio) was related to the control variables: sex (20-35%), age (4-7%), ethnicity (2%), and sport (2%). Fatness is more influenced by sport and by inference training than is the anatomical distribution or patterning of fat on the extremities relative to the trunk. The latter characteristic may be more dependent on biological or environmental factors unrelated to sport and training.

FATNESS, FAT PATTERNING, SKINFOLDS, ATHLETES, PRINCIPAL COMPONENTS, OLYMPICS, SEX DIFFERENCES, ETHNICITY, RACE

Age, sex, and ethnic differences in the physique and body composition of athletes at various competitive levels in a variety of sports have been well documented (3-8,12, 13,15,18,27-30). Little is known, however, about the association of sport and/or event and the relative patterning of subcutaneous fat on the body. Relative fat patterning refers to the distribution of subcutaneous fat on the body and is an individual characteristic relatively uninfluenced by environment (9,10). Fat patterns have been considered in some athletes (18,31), but these efforts have been limited largely to a description of skinfold thicknesses without more detailed evaluation of the fat distribution. In this paper, we examine the relative influence of age, sex, ethnicity/race, and sport on the anatomical distribution or patterning of subcutaneous fat in athletes at the Montreal Olympic Games, 1976.

METHODS

Subjects. The athletes were participants at the Montreal Olympic Games who had volunteered for the anthropometric project (Montreal Olympic Games Anthropological Project). There were 309 males from 46 countries and 147 females from 25 countries. The majority of the athletes were from Europe and those areas inhabited primarily by descendants of Europeans (e.g., United States, Canada, Australia, and New Zealand). The athletes were grouped by ethnicity/race as white, including Caucasians, Latin American Mestizos, East Indians (Indian subcontinent), and those from the Middle East; black, including Africans from south of the Sahara and Afro-Americans from North, Central, and South America, and the Caribbean; and Oriental, including those from Asia or of Asian ancestry living elsewhere. There were 264 white male and 133 white female athletes, 38 black male and 10 black female athletes, and 7 Oriental male and 4 Oriental female athletes. It should be noted that a number of African countries withdrew from the Montreal Olympic Games; as a result, the number of black athletes is relatively small.

Skinfolds. Six skinfolds were measured on each athlete as follows: 1) triceps, on the back of the arm over the triceps muscle at the level midway between the acromial and olecranon processes; 2) subscapular, just beneath the inferior angle of the scapula following the natural contour fold of the skin, i.e., obliquely downward and outward; 3) suprailiac, at a level 5-7 cm above the anterior superior iliac spine on a line to the anterior axillary border and on a diagonal line going downward and inward; 4) umbilical, a vertical fold adjacent to and in line with the umbilicus 3-5 cm to the left; 5) front thigh, midway between the greater trochanter and patella on the anterior midline with the subject's foot resting on a 20-cm stool; 6) medial calf, a vertical fold on the medial side of the leg at the
level of the maximum girth with the subject seated. All skinfolds, except the umbilical, were measured on the right side with a Harpenden caliper, and except as indicated, were measured with the subject standing relaxed. Several technicians measured the athletes over the course of the Olympic Games, however the same technician measured all the sites on an athlete. Tolerance levels, based upon reported variability in the measurements and standard errors of estimate and upon experience, were established (1). All were trained and monitored for quality control by J.E.L. Carter.

**Age.** Female athletes had a median age of 21 yr with a range of 13-30 yr. Male athletes had a median age of 23 yr with a range of 14-39 yr.

**Sport.** There were 20 sports for males and 10 sports for females represented in the sample of athletes. These sports included 68 events for males and 45 events for females. As the samples would be very small in some of the categories, these were synthesized into 12 classes: 1) track and field including runners (running and hurdles) events of less than 3000 m; jumpers, field (shotput, discus, javelin, hammer), and distance runners (events of 3000 m or more); 2) gymnastics (including 2 divers); 3) weight lifting; 4) rowing (including canoeing); 5) ball games (basketball, soccer, handball, volleyball); 6) cycling; 7) wrestling; 8) field hockey; 9) boxing; 10) judo; 11) swimming; and 12) other (including modern pentathlon, fencing, water polo, equestrian, shooting, archery, and yachting). The track and field athletes were grouped for the sake of sample size and because of slight somatotype differences among athletes in different events within each category. A small sample of canoists are included with the rowers as both groups differed only slightly and overlapped considerably in distribution of somatotypes (5). Means and standard deviations for skinfolds and other anthropometric characteristics by sex and sport were reported by Carter (5).

The number of athletes available for study in each of these categories is given later in the report. For analysis of variance involving sport, only classes that would have given five (N = 5) or more individuals in any cell of the analysis were included. Five categories fulfilled this requirement for the female athletes: runners, jumpers, gymnasts, rowers, and swimmers. Among male athletes, all 15 categories were represented by at least five and at maximum 77 individuals per cell. Typically, samples varied between 10-35 per sport/sex category.

**Statistical Methods.** Principal-components analysis was used to identify components of fatness and the anatomical distribution of subcutaneous fat. Two principal components have emerged from previous studies in samples of all ages, in both sexes, and in various ethnic, racial, and/or national groups (20,21,24). The first component typically explains about 70% of the variation, and all subcutaneous fat measurements correlate positively with it. Hence, it is termed a component of fatness. The second component explains about 15% of the variation, and extremity fat measurements correlate positively with it, while trunk sites correlate negatively. Hence, it is termed an extremity/trunk component. Components subsequent to the first two appear to be determined randomly (21).

A principal-components analysis of the six skinfold measurements was done for males and females separately, but for combined age, ethnic, and sport categories. The SPSS program (22) computed principal components from a correlation matrix. This was tantamount to standardizing the variables prior to analysis, such that all skinfolds had unit variance and a mean of zero. Subsequent to the principal-components analysis, individuals were assigned values for each component based on the loadings obtained from the analysis. These were then used in an analysis of variance as dependent variables.

Because of the small numbers of non-white athletes, the effects of age, sex, sport, and ethnicity could not be tested in a single analysis. Rather, the relative effects of sex and ethnicity with age as a covariate were first tested by a two-way analysis of variance. This was done initially because age, sex, and ethnic differences in principal components have already been documented (24). From this analysis in the athletes, it was determined that ethnicity accounted for little of the variation (2-3%) and ethnic groups were therefore combined to test the effects of sex and sport. This resulted, however, in a reduced number of sport categories because only those in which both sexes were adequately represented could be included. Hence, the effects of sport alone were assessed by one-way analysis of variance within each sex separately.

**RESULTS**

The principal-component loadings associated with each skinfold site are shown below for the first two principal components (PC1 and PC2) that emerged from our analysis for Olympic athletes:

\[
\text{PC1}_{\text{male}} = 0.89(\text{triceps}) + 0.86(\text{subscapular}) + 0.87(\text{suprailiac}) + 0.82(\text{umbilical}) + 0.79(\text{thigh}) + 0.79(\text{calf}) \quad (71\%)
\]

\[
\text{PC1}_{\text{female}} = 0.89(\text{triceps}) + 0.83(\text{subscapular}) + 0.79(\text{suprailiac}) + 0.87(\text{umbilical}) + 0.79(\text{thigh}) + 0.78(\text{calf}) \quad (68\%)
\]

\[
\text{PC2}_{\text{male}} = 0.16(\text{triceps}) - 0.36(\text{subscapular}) - 0.31(\text{suprailiac}) - 0.37(\text{umbilical}) + 0.48(\text{thigh}) + 0.48(\text{calf}) \quad (14\%)
\]

\[
\text{PC2}_{\text{female}} = 0.17(\text{triceps}) - 0.37(\text{subscapular}) - 0.48(\text{suprailiac}) - 0.27(\text{umbilical}) + 0.49(\text{thigh}) + 0.48(\text{calf}) \quad (16\%)
\]

The loadings are standardized regression coefficients, which show how each skinfold site is related to the principal component in question. Both the sign and magnitude for each loading are important in the interpretation assigned to the principal component. The percentage variation accounted for by the component is also given.
Clearly, in both sexes the first principal component was fatness and the second was an extremity/trunk distributional component. The former was termed fatness because all skinfolds are positively loaded on it and skinfolds are, perhaps, the most commonly used index of fatness. The latter was termed extremity/trunk ratio as this appears to be the easiest way to conceptualize it. The third component (not given here) differed somewhat due to the small amount of variation accounted for by this component (about 5%). The subsequent analysis thus concentrated on the first two principal components, which collectively accounted for about 85% of the multivariate variance in these skinfold measurements of Olympic athletes.

In order to assess the influence of moderating variables on the principal components, we tested for the effects of sex and ethnicity by two-way analysis of variance with age as a covariate. In this analysis and others in which the sexes are combined, the principal components were computed on the basis of weights obtained in a combined-sexes analysis.

For the first component, sex and ethnicity exerted significant \( (P<0.01) \) effects with no significant interactions. Sex accounted for 20% of the variation in fatness, while ethnicity accounted for only 3%; age was not significantly related to fatness.

For the second principal component (extremity/trunk), sex and ethnicity again exerted significant \( (P<0.01) \) influences; sex accounted for 35% of the variance, and ethnicity accounted for 2% of the variance. When age was entered as a covariate, it accounted for 7% of the variation \( (P<0.01) \), reducing the sex-related variation to 25%, while ethnicity accounted for 2% of the variation.

Figure 1 shows the means \( (\pm \text{S.E.}) \) of the two principal components with regard to the sex/ethnicity analysis of variance. In all ethnic groups the female athletes were fatter than male athletes, and females had a greater extremity-to-trunk fat ratio.

To look into the relationship of sport to the two principal components, a one-way analysis of variance was done with sport as the independent variable and for sexes separately, but combining ethnic groups. A similar analysis was performed for white athletes only in an attempt to control for possible ethnic influences. There was, however, little evidence of such an influence. Fatness (first principal component) was significantly related to sport \( (P<0.01) \) in both sexes; the extremity/trunk fat ratio (second principal component) was not \( (P<0.30) \). Essentially, the same results were obtained when the data were analyzed with ethnic groups combined. These results are shown in Figure 2, which gives the means and standard errors of the two components. With respect to fatness (first component), there were highly significant sport differences, and in all cases except one (swimmers), the trends were identical in both sexes. Runners (short- and long-distance), jumpers, gymnasts, cyclists, and boxers were the leanest, while field athletes, weight lifters, field hockey players, and "other" athletes were the fattest. Rowers and swimmers tended to be slightly fatter than others, whereas ballgame players and judo participants fell close to the mean of the population. The only difference by sex (note that the analysis was done for each sex separately) was in swimmers. Female swimmers tended to be fatter than the overall average, while male swimmers tended to approximate the mean. Hence, there may be a sex-by-sport interaction for this particular sport.

There were few sport differences in the extremity/trunk component (second principal component) shown in the lower half of Figure 2. Few of the means of the extremity/trunk component for specific sports or events differed significantly from the population mean. The only clear difference appeared among jumpers, who tended to have a lower extremity/trunk ratio of fat. The apparent sex difference in this component among short-distance runners was probably a result of the fact that most male runners in the sample are black athletes, and hence had a somewhat lower ratio. Weight lifters also seemed to have a lower extremity/trunk ratio of fat than other athletes, but less confidence can be placed in this trend because of the small sample (N=11). The overall sport effect F-ratios for the fatness component were \( F=7.10, \text{df}=14, 294 \) (males) and \( F=16.18, \text{df}=4, 133 \) (females) (both \( P<0.01) \); and for the extremity/trunk ratio component were \( F=1.96, \text{df}=14, 294 \) (males) and \( F=0.30, \text{df}=4, 133 \) (females) (both \( P<0.05) \).

For the one-way analysis of variance shown in Figure 2, an assumption is equality of variances (22). These F-ratios of heterogeneity of variances were significant \( (P<0.01) \) for both principal components in each sex, sug-
suggesting that some sports were highly variable while others were less so in these principal components of fatness. The effects of sport on individual variation in the two principal components are shown in Table 1, in which the distribution of sport by standard deviation class is shown. The expected standard deviation is 1.0 for both components. Three classes are shown: standard deviation less than 0.75, 0.75-1.25, and greater than 1.25. Except for swimmers, the trends were similar in both sexes. Runners (short- and long-distance), jumpers, gymnasts, ballgame players, cyclists, and boxers tended to be less variable in both components than other sports. Weight lifters, wrestlers, swimmers, and field hockey players tended to be the most variable, with rowers and field athletes being intermediate in variability. The sports in which there was greater variation tended to consist of different weight subclasses as in weight lifters and wrestlers.

Sports or events more variable in the first component also tended to be more variable in the second component; likewise, those less variable in one component tended to be so in the other. This was particularly so for female athletes. However, there were several exceptions. Among males, swimmers ranged from the least variable in fatness to the most variable in extremity/trunk ratio. In wrestlers, the trend was reversed. The variance differences among sports did not negate a significant effect of sport on the means of the fatness component because the mean differences were statistically significant at a very high level (P<0.01). These variance differences clouded the interpretation of effects of sport on the trunk/extremity component because the latter reached only the P=0.05 level of statistical significance and indeed were not significant in the analysis of white athletes only.

In order to equalize variances among sport classes, indices based upon the natural logarithms of skinfold measurements were constructed. The log transformation of

![Figure 2—Means (± S.E.) of scores computed from the first two principal components of subcutaneous fat variation by sport for each sex separately (ethnic groups combined).](image_url)

### Table 1. Inter-individual variation in fatness and extremity/trunk patterning of fat by sport and/or event (age and ethnic groups combined) among athletes at the Montreal Olympic Games.

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<td>0.75-1.25</td>
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Listed are sports/events and the values of the standard deviation under which they fall. The expected standard deviation is 1.0.
data is useful when the mean and variance are correlated (26). Unfortunately, the principal components cannot be directly log-transformed because some individuals would have mean values of zero or less. Hence, simple indices, which are correlated to the two principal components but comprised of the least number of skinfolds (log-transformed), were constructed as follows:

Fat Index = log triceps skinfold

Pattern Index = log medial calf skinfold

log subscapular skinfold

The fat index correlated with the first principal component by 0.86 in both sexes, while the pattern index correlated with the second principal component by 0.73 in males and 0.76 in females. Thus, these indices are related to the principal components and yet are in a form that can utilize log-transformed values.

A one-way analysis of variance among white athletes using the above indices was successful in removing heterogeneity of variances, except in the pattern index for male athletes. In this group, heterogeneity of variance remained, but at a barely statistically significant level ($P<0.05$). There was a highly significant ($P<0.01$) effect of sport on the fat index in both sexes, and the means followed the trends shown in Figure 2. Sport accounted for approximately 16-30% of the variation in fatness. The overall sport effect $F$-ratios for the fatness index were $F = 3.88$, $df = 14$, 249 (white males) and $F = 13.50$, $df = 14$, 120 (white females).

The pattern index was also related to sport among white female ($P<0.01$) and white male athletes ($P<0.05$). Swimmers of both sexes had the highest extremity/trunk ratio, while runners and jumpers had the lowest. The apparent male/female difference in extremity/trunk ratio among swimmers, seen in Figure 2 and referred to earlier, disappears when variances are made homogeneous. Otherwise, the trends evident in the lower half of Figure 2 correspond well with the pattern index based on log-transformed skinfold measurements. Sport appears to account for about 10% of the variation in the pattern index. The overall sport effect $F$-ratios for the pattern index were $F = 1.87$, $df = 14$, 249 (white males) and $F = 3.57$, $df = 14$, 120 (white females).

Because sex explained a major amount of variation in the two principal components, the effect of sport relative to that of sex was examined through a two-way analysis of variance of sex and sport effects with age as a covariate (Table 2). Again, ethnic groups were combined, although a similar analysis, obtaining similar results, was done on white athletes only. For the first principal component (fatness), sex accounted for 30.1% of the variation and sport accounted for 18% of the variation (top, Table 2). Adjusting for age altered these percentages negligibly (bottom, Table 2). For the second principal component (extremity/trunk), sex accounted for 40% of the variation and sport for only 2% of the variation (the latter significant at $P<0.05$). Adjusting for age (bottom Table 2) changed the importance of sex slightly: age, 4%; sex, 35%; and sport, 2%. There were no sex-by-sport interactions on either of the components. Figure 3 illustrates the mean trends. The number of sport categories was, of course, reduced to those in which there were sufficient numbers of both sexes for analysis. Clearly, rowers and swimmers were fatter than runners, jumpers, and gymnasts, the sex-differences being maintained in all sport categories. For the extremity/trunk

<table>
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<th>Sex-by-Sport Interaction</th>
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*P<0.05  **P<0.01
bution component, was considered. Other studies have assessed fatness differences among athletes in different sports and/or events (7,13,18,27,31). Only Yuhasz (31) has addressed the issue of fat patterning differences among athletes participating in different sports and/or events. Using only graphic comparisons of mean skinfold thicknesses for 7 or 15 skinfold sites, Yuhasz noted that athletes did not differ in fat pattern when grouped by sport and sex; rather, individual variation was the rule. No statistical evaluation of the fat patterns, however, was offered. The present study considered differences in fatness as measured by skinfolds among athletes in a larger number of sports and/or events and in the anatomical distribution or patterning of subcutaneous fat. In contrast to the lack of fat patterning differences by sport and sex noted by Yuhasz (31), our results indicated that the second principal component (distribution of fat on the extremities relative to the trunk) was significantly influenced by sex and only slightly influenced by sport, while the first principal component (fatness) was significantly influenced by sex and sport (see below).

Among the sample of Olympic athletes, results of the principal-components analysis demonstrated the same components that have been previously described in many populations (21). Notable were the almost equal values of the loadings for the thigh and calf skinfolds on the second principal component. In non-athletic samples, the calf consistently loaded somewhat higher than the thigh skinfold on this component. The similarity of loadings in the present study may be specific to samples of athletes.

Sport can be treated as a special environmental variable and the other three control variables (sex, age, and ethnicity) as biodemographic variables. Sport is “special” in the sense that a sample of Olympic athletes is a highly selected group and is “environmental” because training is a modification of the environment made in preparation for competition, although there are possible genetic influences on physique, body composition, and performance (2,16,17). What, for example, are the relative effects of each of these variables on fatness and fat patterning?

The first principal component was associated with the control variables in descending order as follows: sex (21-31%), sport (19%), ethnicity (3%), and age (1-3%). Sport accounted for almost as much of the variation as sex and much more than ethnicity and age. This suggests that either regular physical activity, such as training for sport, is likely to affect one’s overall fatness, that the amount of body fat may influence proficiency in sport, or some combination of these. The fact that our “other” category of athletes was significantly fatter than those in more active sports suggests that in this case, differences in physical activity produced different levels of fatness, a finding that is not surprising. However, those involved in vigorous aquatic sports (swimming and rowing) were significantly fatter than track athletes, gymnasts, and cyclists. Perhaps the additional fat is not a handicap in these aquatic sports.

**DISCUSSION**

By using principal components instead of specific skinfold thicknesses or sums of skinfold thicknesses, the association of sport and the two principal components that explain a major part of the variation in subcutaneous fat, i.e., the fatness component and extremity/trunk distri-

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Figure 3—Means (± S.E.) of scores computed from the first two principal components of subcutaneous fat variation by sex and sport (ethnic groups combined).
and/or may reflect a selection factor, especially for body size and mass.

Female athletes were fatter than male athletes in all sport categories in which comparisons could be made. Thus, there are important biologic influences that override or are as important as sport itself in determining individual fatness. The male/female differences among these athletes were of the magnitude of those seen in non-athletic populations (19).

Although black athletes were leaner than other ethnic groups, this difference was relatively minor compared to the effects of sex and sport on fatness. Factors, genetic or otherwise, that contribute to between-population differences in fatness are apparently unimportant in determining ability to perform in various sports. In fact, athletes from different ethnic/racial groups participating in the same sport or event are often more similar than different in physique (27).

The anatomical distribution of fat on the extremities relative to the trunk, the second principal component, was associated with the control variables in descending order as follows: sex (28-35%), age (4-7%), ethnicity (2%), and sport (2%). In contrast to fatness, biometric and environmental variables were more important than sport in the second principal component, and of these, sex was the single most important one. This suggests that the major component of fat patterning is biological rather than environmental. Evidence for this conclusion is also apparent in previous genetic and epidemiologic studies (9,10,20). However, environmental changes during growth may also affect the anatomical distribution of fat. This suggests the possibility of genotype-environment interactions during sensitive developmental periods (24).

While ethnic group differences accounted for little variation in both principal components, it is clear in Figure 1 that they follow expectations. Blacks were leaner than whites and probably leaner too than Orientals, and whites had the highest extremity/trunk ratio of fat. Orientals had the lowest, with blacks intermediate. These results have been repeatedly shown in other studies of athletes (29) and non-athletes (11,14,19,24,25). It is interesting that sex and ethnic group differences in fatness and the relative distribution of fat on the extremities and trunk persisted among Olympic athletes.

In Figure 2, the overall test for effects of sport on extremity/trunk patterning of fat was significant \(P < 0.05\), but the variance differences by sport must be considered. It was evident that some of the sport means differ substantially from each other. Jumpers and weight lifters, for example, had less fat on the extremities relative to what they had on the trunk than rowers who tended towards the opposite. It may be fruitful to focus on the selection and/or training of jumpers and weight lifters in seeking factors that contribute to concentration of fat on the trunk.

In summary, results of the principal-components analysis of subcutaneous fat suggested that fatness, the first principal component, was more influenced by sport and by inference training than was the anatomical distribution or patterning of fat on the extremities relative to the trunk, the second principal component. The latter characteristic may be more dependent on biological (genetic) factors per se or perhaps environmental factors unrelated to sport and training.

The biological significance of sex and ethnic differences in the anatomical distribution of fat can be debated. Pond (23) has suggested two factors that favor a centralized fat distribution: 1) mechanical efficiency and 2) changes in sexual signaling over the life cycle. Looking at fat patterning with respect to sport could address the first factor. We have not examined fat patterning in athletes as a whole compared to the general less active population to see whether among athletes there is a tendency toward a more central distribution of fat. However, to the extent that different sports or events require different types of mechanical efficiency, the mild overall influence of sport on subcutaneous fat patterning lends little support for mechanical efficiency being an important ecological determinant of fat patterning. As a caution to this conclusion, however, Olympic short-distance runners and jumpers of both sexes and male weight lifters had the most centrally distributed fat, while individuals in aquatic events (where buoyancy may be a significant factor) had the most extremity-oriented fat distribution.

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