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# SHAPING OF THE FOOT ARCH AND FULL-TIME SPORT ACTIVITIES

*ABSTRACT — The study is concerned with foot formation in persons subjecting their feet in various ways to intense load. 680 males and 460 females, actively engaged in sport activities for a long time were subjected to thorough plantographic and fluorescent pedobraographic examination. According to the load men were divided into 34 groups and women into 23 groups covering a wide range of sports and competitive games.*

*In comparison with the general population the mean results correspond to the standards. In the sense of longitudinal arching they have somewhat lower, and in the transverse sense somewhat higher arches than the general population. Lower foot arch is typical of sprinters, high jumpers, pole jumpers, basketball players and gymnasts and modern gymnasts. Lower foot arch is typical of weight lifters, fencers, long jumpers, Marathon racers, Alpine skiers and table-tennis players.*

*The discussion stresses the importance of primary foot formation. It includes also the results of the examinations of the world's best sportsmen and also mentions data from a number of authors. In conclusion it contains various ways of using the results in the practice, in the evaluation of foot formation,its influencing by varying sporting load and application in the prevention of defective foot formation, both in active sportsmen and in the general population.*

*The foot formation of man is a characteristic, but to a certain extent also specific phenomenon. The dominating feature is the inborn genetic inclination. For these reasons the findings in adulthood cannot be interpreted without a reliable knowledge of the situation in the youth. Without such a knowledge it can be explained only as a phenomenon appearing more or less frequently in connection with a certain load. Only a long-term study of the individuals can explain the influence of a certain load on foot formation, both in the positive and in the negative sense. At the same time increased flattening is not always prognostically unfavourable, as it was in this paper. It is documented also by a recently published paper by Linc (1985). On studying the electric activity of the shin muscles in connection with foot formation in sportsmen he did not find worse functional effect in subjects with lowever foot arch.*

*KEY WORDS: Foot formation — Morphological adaptability — Sports medicine — Functional anthropology.*

The foot, the basic means of human locomotion is lightly at the centre of interest, both of laymen and of scientists. Similarly as with other organs man realizes its importance only with the appearance of troubles and tries to find remedy. As a rule it is not an easy matter, and in some cases it is even impossible. That's why we find in the scientific literature many works dealing with the formation of foot and its relations to a great variety of factors in human life.

Most often, obviously enough, the clinical aspects are followed. This is the case e. g. with the older works by Balakirev (1929), Morton (1935), Bogdanov (1953), Hohmann (1961), and by many other foreign, as well as Czech authors, including such renowned orthopedists as Zahradníček (1955), Jaroš (1953, 1963), Hněvkovský (1960) and others who drew attention to the rising number of flat foot findings. As the most frequent cause of flat foot brought forward is the phenomenon

people call civilization, comprising a wide range of causes such as the changing way of life, nutrition, footwear, improper loading of the foot during work, etc. This conception, however, doesn't cover the whole fact. Flat foot occurs as a general character also in quite primitive tribes not using any footwear. If we stick to the deduction that the foot arch has developed in the phylogenesis, first of all as a mechanism enabling elastic movement, the findings of flat-foot and the complaints connected with it are a good reason for a deeper analysis of the whole problem.

On dealing with the problem special attention was paid to the methods of foot examination. Objectively roentgenography was used most frequently for foot evaluation; in the practice however, also simpler methods are applied due to lower demands, such as direct examination, but also plantographic, and recently pedobarographic methods were used. Morton (1935) draws our attention also to other possible ways of foot arch examination, namely with the help of a staticometer, kinetograph and barograph. Pisani (1973) describes in several studies the pedostratigraph providing for the combination of radiological examination with plantographic picture, photopedogram and pressopedogram. A number of other methods complete the possibilities. The basic proposal for the evaluation of plantograms by assessing first of all the angle covering the transverse arch formation have been worked out by Schwartz and his collaborators (1928), and later by Chippaux (1947) was based on calculating the index from the plantogram which, on the contrary, expresses first of all the shape of the longitudinal foot arch. Clarke (1933) — in a comprehensive analysis of plantograms — recommends on the basis of Schwartz principle of proceeding, a double evaluation of this angle.

In the Czech literature it was Šmířák (1960) who used Chippaux' method with some adjustments and elaborated an extensive study on foot formation in school youth and apprentices. Klementa continued in this trend (1964, 1966, 1967, 1969). He elaborated a complex of works — up to now the most extensive in this country — focusing on the problem of the feet in young people, especially of those working manually. He drew attention in this respect to various types of apprentice training. At the same time (1969) he checked the methodical proceedings and put forward a number of improvements. Bavor and Hořava (1974) have chosen a particularly interesting approach to the evaluation of foot arch. Their views are based on the assumption that the foot arch has developed phylogenetically, among other things as a protection of the neuro-vascular bunch against being compressed. On the basis of an anatomical study they specified 4 types of blood supply to the planta through vessels and they compared these with types of X-ray findings by other authors and reached a remarkable accord of views. We cannot mention here all works, either by foreign or Czech authors who dealt with the problem.

The Institute of Sports Medicine, Med. Fac. in Prague also paid considerable attention to methodical questions regarding the taking and evaluation of plantograms (Novotný 1965) and by introducting the pedobarographic method (Choděra 1957) to the sports medicine (1965). These methods have become routine part of the medical examination of sportsmen and of patients and are currently used also in the scientific-research work. This lead also to the studies on foot formation in university and college students, in the Czechoslovak adult population, in elderly people, and also to studies on foot formation in people with great sport load.

The results of many scientific works on foot formation stress the importance of the static and dynamic load influencing foot formation, both in the positive and in the negative sense. Besides the primary genetic factor foot formation is considerably influenced by the regime of life of modern man, by new ways of subjecting the foot to load. Sporting activities play quite a special role in this context. The intentional increase of man's performance loads the foot in quite a specific way. The demands are very high in this respect and the variability of unequal load in various sports offer us a unique opportunity not only to detect the mere consequences of a certain load on foot formation, but its results can be used for prevention, through specially oriented training also in the general population, in patients that need some adjustment in this direction.

The extensive material covering the 1960—1985 period documents graphically the foot formation in sportsmen loading their feet one-sidedly for many years and has enabled us to evaluate these findings from the anthropological, as well as from the sports-medical point of view. On the basis of this material we were also able to prepare our first complex report on foot formation in connection with intense load on foot at various sport activities continuing for many years.

## METHOD

1. Object of the research:

a) The examination included a group of 680 men aged 17—34 years and of 460 women within the 16—31 age bracket, all full-time sportsmen and sportswomen. They all reached the so-called "first class" or "champion class" efficiency or were members of teams playing in the first Czechoslovak league in their respective sport, most of them were at the same time Czechoslovak representatives in their respective sport. The time span of their top sporting activities ranged from 4 to 12 years. According to the type of sport men were divided into 34 groups and women into 23. The research covered almost all events.

b) The results of the examination of the population sample realized by us (Novotný 1976) served as a control set (from group IBP-HA); the control set contained males and females at the age of 25 years.

2. Method of examination:

a) The aspect and palpation of the foot (Katzer 1963)

b) Pedobaroscopy (Choděra 1957)

c) Plantography (Novotný 1965). The evaluations of the plantograms was realized with the help of Chippaux index (1947) and of the angle proposed by Schwartz (1928).



3. The statistical processing of the results was realized by the Cybernetic Department of the Medical Faculty, Charles University in Prague.

## RESULTS

The complex results of the examination of all sportsmen and sportswomen is within the norm. The mean value of Chippaux' index in the right foot of the sportsmen was 32.79 ($s = 3.13$), and in the left foot 31.78 ($s = 3.45$); the respective mean values in sportswomen were 30.46 ($s = 2.80$) and 28.57 ($s = 3,37$). These results are slightly above the mean value of the population corresponding in age (men 30.28—29.99, women 28.55—26.31), that means that they correspond to a somewhat lower foot arch in the longitudinal sense. The average value of Schwartz' angle in the sporting men was 44.15° ($s = 3.69$) in the right foot and 43.65° ($s = 4.16$) in the left, and in sporting women 45.43° ($s = 2.61$) and 44.41° ($s = 2.37$) respecti-

TABLE 1. *Survey of the results of the foot formation in top sportsmen*

| Men | Index of Chippaux | | | |
|---|---|---|---|---|
| | right foot | | left foot | |
| Sports Events | $\bar{x}$ | $s$ | $\bar{x}$ | $s$ |
| 1. Cycling | 26.75 | 11.1 | 23.10 | 14.4 |
| 2. Athletics-pole vault | 27.36 | 10.7 | 27.30 | 11.0 |
| 3. Basketball | 28.29 | 12.7 | 27.90 | 16.0 |
| 4. Athletics-runners 100—200 m | 29.62 | 7.7 | 26.94 | 9.7 |
| 5. Ice hockey | 29.24 | 6.3 | 27.35 | 10.3 |
| 6. Athletics-high jump | 30.72 | 8.6 | 27.15 | 11.8 |
| 7. Skiing, cross country | 27.92 | 16.0 | 30.63 | 13.2 |
| 8. Tennis | 30.60 | 10.4 | 29.37 | 9.2 |
| 9. Boxing (60—70 kg) | 32.91 | 18.5 | 27.90 | 18.5 |
| 10. Boxing (75—100 kg) | 33.50 | 10.4 | 28.96 | 10.3 |
| 11. Handball | 31.44 | 7.7 | 31.04 | 7.3 |
| 12. Rowing | 32.48 | 10.5 | 30.06 | 12.0 |
| 13. Swimming | 31.88 | 7.2 | 30.96 | 9.8 |
| 14. Land hockey | 32.48 | 9.3 | 30.77 | 15.1 |
| 15. Rugby | 31.54 | 14.4 | 31.77 | 11.2 |
| 16. Volleyball | 31.42 | 12.6 | 32.08 | 13.3 |
| 17. Modern penthathlon | 32.67 | 12.2 | 30.84 | 12.6 |
| 18. Canoeing | 32.26 | 6.1 | 31.30 | 11.8 |
| 19. Athletics-long jump | 32.48 | 8.8 | 32.56 | 8.4 |
| 20. Athletics-runners 400—1 000 m | 32.23 | 12.6 | 32.89 | 14.6 |
| 21. Judo | 32.22 | 11.1 | 33.26 | 10.7 |
| 22. Athletics-competitive walking | 32.52 | 11.1 | 33.25 | 11.8 |
| 23. Athletics-Marathon | 32.46 | 12.9 | 34.26 | 11.7 |
| 24. Athletics-runners 5 000—10 000 m | 33.49 | 8.9 | 32.71 | 10.7 |
| 25. Football | 33.20 | 9.4 | 34.27 | 12.2 |
| 26. Figure-skating | 34.59 | 10.2 | 33.66 | 13.2 |
| 27. Water-polo | 36.23 | 10.9 | 32.99 | 11.8 |
| 28. Skiing, Alpine | 36.00 | 10.4 | 34.45 | 16.0 |
| 29. Athletics-discus throwing | 36.97 | 7.9 | 35.48 | 11.7 |
| 30. Fencing | 36.15 | 8.1 | 36.98 | 9.9 |
| 31. Athletics-javelin throwing | 37.98 | 8.2 | 35.37 | 11.3 |
| 32. Weight-lifting (60—82.5 kg) | 37.26 | 7.6 | 36.50 | 9.7 |
| 33. Table-tennis | 38.25 | 7.4 | 37.29 | 9.5 |
| 34. Weight-lifting (82.5—) | 39.94 | 8.2 | 39.15 | 9.0 |

TABLE 2. *Survey of the results of the foot formation in top sportsmen*

| Men | Angle of Schwartz | | | |
|---|---|---|---|---|
| | right foot | | left foot | |
| Sports Events | $\bar{x}$ | $s$ | $\bar{x}$ | $s$ |
| 1. Basketball | 51.10 | 11.1 | 49.05 | 11.6 |
| 2. Swimming | 51.10 | 7.3 | 45.85 | 8.2 |
| 3. Canoeing | 48.30 | 6.8 | 47.00 | 8.3 |
| 4. Rowing | 46.95 | 9.7 | 47.85 | 8.0 |
| 5. Cycling | 47.95 | 6.9 | 46.55 | 6.3 |
| 6. Judo | 48.20 | 10.4 | 46.15 | 8.6 |
| 7. Athletics-pole vault | 49.35 | 5.4 | 44.90 | 6.5 |
| 8. Modern pentathlon | 45.90 | 9.3 | 46.90 | 8.5 |
| 9. Rugby | 46.45 | 10.5 | 46.05 | 8.4 |
| 10. Athletics-high jump | 46.25 | 7.9 | 46.15 | 8.4 |
| 11. Ice hockey | 46.00 | 5.7 | 45.85 | 7.0 |
| 12. Tennis | 45.60 | 9.8 | 46.20 | 10.3 |
| 13. Land hockey | 47.10 | 7.9 | 44.20 | 10.2 |
| 14. Athletics-runners 100—200 m | 46.15 | 6.5 | 44.95 | 6.6 |
| 15. Water-polo | 45.40 | 7.6 | 44.80 | 6.1 |
| 16. Handball | 46.05 | 6.4 | 43.15 | 7.0 |
| 17. Athletics-long jump | 44.90 | 9.9 | 43.95 | 8.2 |
| 18. Boxing (75—100 kg) | 43.05 | 6.8 | 45.50 | 6.8 |
| 19. Volleyball | 44.30 | 10.6 | 42.80 | 10.5 |
| 20. Athletics-runners 5 000—10 000 m | 44.20 | 7.7 | 42.55 | 8.4 |
| 21. Fencing | 43.60 | 12.1 | 43.10 | 13.3 |
| 22. Skiing cross country | 43.40 | 9.4 | 42.50 | 12.8 |
| 23. Football | 42.95 | 8.4 | 40.25 | 10.3 |
| 24. Athletics-competitive walking | 42.15 | 9.8 | 40.05 | 11.9 |
| 25. Boxing (60—70 kg) | 40.40 | 13.1 | 41.75 | 15.0 |
| 26. Athletics-runners 400—1 000 m | 42.75 | 10.6 | 39.20 | 12.4 |
| 27. Athletics-javelin throwing | 39.85 | 10.4 | 40.10 | 10.1 |
| 28. Weight-lifting (60—82.5 kg) | 40.80 | 9.7 | 38.80 | 10.7 |
| 29. Athletics-discus throwing | 38.10 | 11.4 | 41.05 | 9.4 |
| 30. Table-tennis | 38.30 | 7.1 | 38.70 | 7.8 |
| 31. Athletics-Marathon | 38.60 | 8.6 | 38.05 | 11.2 |
| 32. Figure-skating | 39.70 | 9.0 | 36.70 | 10.8 |
| 33. Weight-lifting (82.5—) | 38.30 | 7.3 | 36.90 | 10.8 |
| 34. Skiing, Alpine | 38.00 | 12.6 | 36.60 | 15.5 |

vely. These values are slightly above the mean values in both sexes of the control group (men 43.27—41.51, women 42.58—42.54), but their inverse meaning shows somewhat better foot arch in the transversal sense than in the case with the general population.

The placing of the results obtained from the control groups in a tabular summary of results is very much in line with the above results. At evaluating the longitudinal foot arch the norm comes into the first third of the sporting group, at evaluating the transverse arch, the norm falls into the third third of the group of all sportsmen. That means that the majority of sporting people have the value of Schwartz angle more favourable than is the case in the sample of the population.

As regards the differencies between the right and left foot it is in sporting people similar as in the sample of the population. The index of the longitudinal arch in the left foot is of lower value, i.e. it is more favourable. In men it is without significance, in women from the population the significance is on the $p < 0.01$ level and in sports women on the $p < 0.05$ level. The angle of the transversal arch brings opposite results.

However these differences have no statistical significance in sportsmen and sportswomen, while in the sample of the general population in males it is on the level of $p < 0.01$. The results are well perceptible in *Tables 1—4.*

In men the most favourable transverse foot arch values have been measured in cyclists, basketball players and in athletes competing in high jump, pole-vault and in sprinters. The least favourable results in this respect were found in weight-lifters, athletes javelin and discus throwers, table-tennis players and fencers. The best transversal arch values have been measured in basketball players, cyclists, swimmers, canoeists and rowers, while the least favourable results have been obtained in the group of weight-lifters, table tennis players, Alpine skiers, figure-skaters and Marathon runners.

TABLE 3. *Survey of the results of the foot formation in top sportswomen*

| Women | Index of Chippaux | | | |
|---|---|---|---|---|
| | right foot | | left foot | |
| Sports Events | $\bar{x}$ | $s$ | $\bar{x}$ | $s$ |
| 1. Gymnastics | 25.56 | 10.1 | 20.48 | 13.8 |
| 2. Modern gymnastics | 25.92 | 12.5 | 21.83 | 13.2 |
| 3. Tennis | 25.51 | 11.8 | 25.89 | 12.0 |
| 4. Handball | 26.68 | 9.0 | 24.99 | 9.8 |
| 5. Rowing | 26.04 | 14.5 | 28.72 | 12.8 |
| 6. Athletics-runners 1,500 m | 31.63 | 9.4 | 25.53 | 14.5 |
| 7. Figure-skating | 29.77 | 12.7 | 27.65 | 11.5 |
| 8. Fencing | 29.43 | 4.6 | 28.06 | 7.9 |
| 9. Land hockey | 31.05 | 9.2 | 27.46 | 12.9 |
| 10. Basketball | 32.25 | 13.6 | 26.61 | 16.6 |
| 11. Athletics-pentathlon | 33.10 | 9.6 | 26.54 | 16.0 |
| 12. Athletics-runners 100—200 m | 30.59 | 5.4 | 29.09 | 7.1 |
| 13. Skiing, cross country | 30.59 | 11.3 | 29.19 | 10.6 |
| 14. Athletics-high jump | 31.49 | 11.6 | 29.20 | 12.2 |
| 15. Volleyball | 31.26 | 10.2 | 29.93 | 12.9 |
| 16. Athletics-shot-put | 29.93 | 9.4 | 31.69 | 6.3 |
| 17. Athletics-runners 400—800 m | 32.83 | 10.7 | 29.73 | 11.6 |
| 18. Swimming | 30.49 | 8.7 | 32.15 | 11.5 |
| 19. Skiing, Alpine | 30.81 | 11.5 | 32.09 | 11.5 |
| 20. Judo | 32.13 | 9.4 | 31.49 | 6.7 |
| 21. Athletics-long jump | 33.44 | 10.8 | 31.81 | 14.6 |
| 22. Canoeing | 34.05 | 6.9 | 32.32 | 10.3 |
| 23. Football | 36.12 | 8.2 | 34.74 | 9.3 |

TABLE 4. *Survey of the results of the foot formation in top sportswomen*

| Women | Angle of Schwartz | | | |
|---|---|---|---|---|
| | right foot | | left foot | |
| Sports Events | $\bar{x}$ | $s$ | $\bar{x}$ | $s$ |
| 1. Gymnastics | 49.50 | 5.6 | 49.05 | 6.1 |
| 2. Athletics-shot put | 50.40 | 6.7 | 47.55 | 5.9 |
| 3. Handball | 48.70 | 5.0 | 47.50 | 4.8 |
| 4. Athletics-runners 100—200 m | 48.65 | 8.8 | 47.35 | 5.9 |
| 5. Modern gymnastics | 47.95 | 5.2 | 47.30 | 6.3 |
| 6. Swimming | 49.00 | 9.4 | 45.20 | 8.5 |
| 7. Rowing | 46.55 | 4.6 | 46.85 | 6.9 |
| 8. Volleyball | 47.05 | 7.6 | 45.30 | 8.5 |
| 9. Lawn tennis | 45.95 | 8.4 | 44.40 | 7.7 |
| 10. Judo | 44.11 | 12.0 | 45.56 | 11.4 |
| 11. Figure-skating | 45.45 | 7.8 | 43.75 | 7.3 |
| 12. Skiing, Alpine | 45.70 | 6.9 | 43.50 | 8.1 |
| 13. Basketball | 44.35 | 11.2 | 44.85 | 9.6 |
| 14. Athletics-runners 1,500 m | 44.40 | 8.9 | 44.50 | 7.4 |
| 15. Athletics-high jump | 44.35 | 10.5 | 42.75 | 9.4 |
| 16. Athletics-runners 400—800 m | 43.85 | 7.5 | 43.05 | 8.2 |
| 17. Skiing, cross country | 43.70 | 12.8 | 42.90 | 9.4 |
| 18. Land hockey | 41.90 | 8.9 | 44.40 | 5.4 |
| 19. Fencing | 44.33 | 5.0 | 41.89 | 6.7 |
| 20. Athletics-pentathlon | 44.20 | 8.6 | 41.30 | 10.3 |
| 21. Canoeing | 42.25 | 8.0 | 41.35 | 7.1 |
| 22. Athletics-long jump | 41.75 | 11.9 | 40.75 | 11.6 |
| 23. Football | 40.85 | 10.8 | 40.45 | 12.4 |

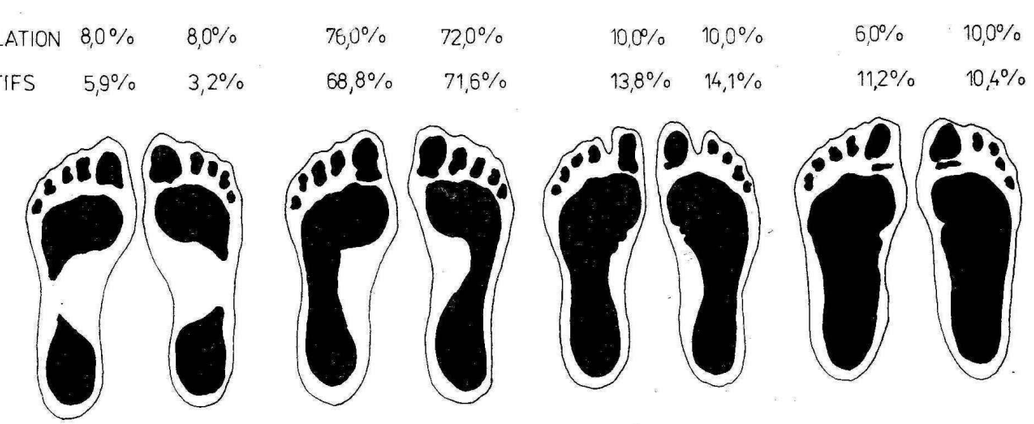


FIGURE 1. *Foot formation in top sportsmen. (34 sports events)*



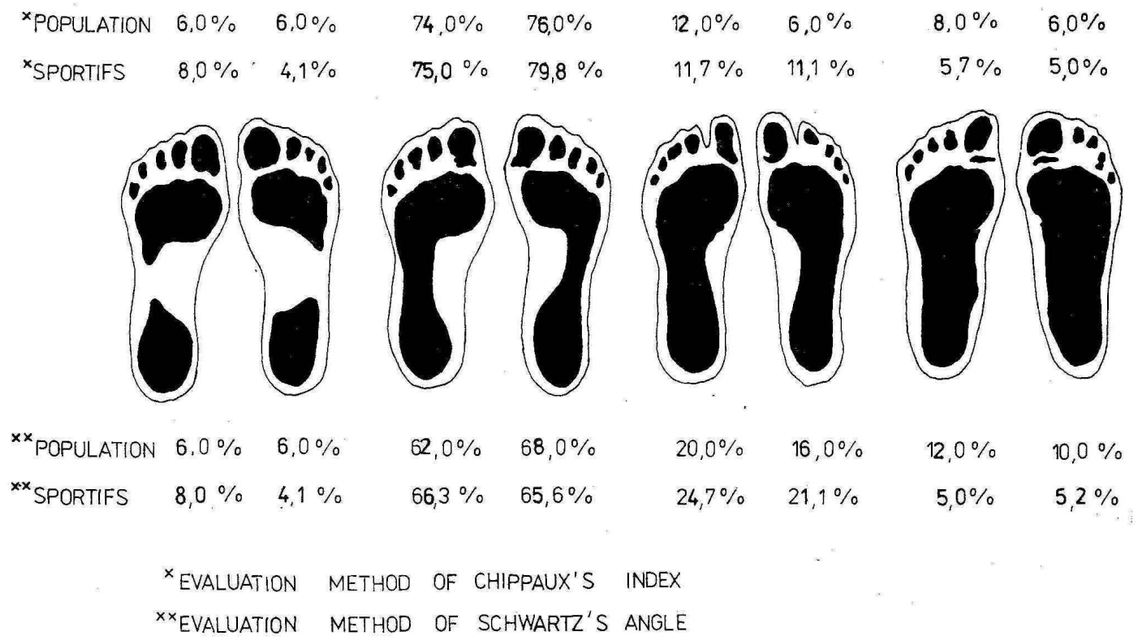


FIGURE 2. *Foot formation in top sportswomen. (23 sports events)*

In the group of women the most favourable transversal arch values have been measured in the group of. gymnasts, modern gymnasts, tennis and handball players. The least favourable results were obtained in the group of football players, long jumpers, Alpine skiers and canoeists. The highest transversal arch values in the group of women were measured in gymnasts, sprinters, hand-ball players and weight-hutters. The lowest angle value, i.e. the least favourable results come from the group of football players, canoeists, fencers and athletes competing in long jump and in pentathlon.

The differences between the right and left foot in the individual sports are apparent from the tables, but they have no statistical significance.

The share of various forms of foot formation in the individual groups remains hidden behind the total numbers. The proportion of the high, normal, slightly flat and flat feet in the given population sample and in all the studied sportsmen is graphically presented in *figures 1—2.* In the group of sporting men we can see a slight occurrence of foot arches regarded as high. In sporting men we can see a small proportion of feet with high arch. In the longitudinal arch the proportion of feet with normal arch is smaller, while the percentage of slightly flat or flat feet is higher. The situation is similar also in the transversal arch, with the only difference that the right foot is better represented in the group of normally arched feet and the proportion of flatfness is lower in both feet.

In the group of sporting women the results are very close to the results observed in the population sample, with the difference that in both evaluation methods the proportion of normal arch in the group of sporting women is higher, while the proportion of flat feet is lower than is the case with men. The difference between right and left feet is greater in the group of sporting people than in the sample of the general population.

The detailed results of this division according to the foot formation in the individual groups are presented in *Tables 5—6.* The results show that sprinters, ice-hockey players boast the highest percentage of normal foot formation and none of them have flat foot. On the other hand very few weight-lifters have normal longitudinal foot arch; they are by the way heavily represented among sportsmen with flat foot. The group of table-tennis players and Alpine skiers had only slightly better results.

The largest number of normal transverse foot arch was found among swimmers, while the smallest number of sportsmen with normal transverse foot arch is to be found in the group of weight lifters, table-tennis players and Alpine skiers; the latter, along with discus-throwers had a high percentage of flat feet.

A similar evaluation of foot formation in sporting women shows that the highest number of normal foot arch according to Chippaux index, similarly as in men, is in sprinters and the smallest number of normal foot arch is to be found in the group of pentathlonists. In the group of sportswomen the largest proportion of slightly flattened and flat feet was found in the group of football players, long jumpers and kayakers.

According to the Schwartz angle evaluation the

TABLE 5. *Frequency of various foot formation (in %) in top sportsmen (A — Method of Chippaux, B — Method of Schwartz)*

| Foot arch | Normal | | | | Slightly flattened | | | | Flat | | | | Hight | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Method | A | | B | | A | | B | | A | | B | | | |
| Foot | right | left | right | left | right | left | right | left | right | left | right | left | right | left |
| *Sports events* | | | | | | | | | | | | | | |
| Boxing (60—70 kg) | 70 | 65 | 55 | 55 | 5 | 5 | 25 | 15 | 15 | 15 | 10 | 15 | 10 | 15 |
| Boxing (75—100 kg) | 75 | 80 | 55 | 65 | 10 | 15 | 35 | 30 | 10 | 0 | 5 | 0 | 5 | 5 |
| Canoeing | 85 | 65 | 80 | 70 | 15 | 15 | 20 | 25 | 0 | 15 | 0 | 0 | 0 | 5 |
| Ice hockey | 90 | 90 | 70 | 65 | 10 | 0 | 30 | 25 | 0 | 0 | 0 | 0 | 0 | 10 |
| Basketball | 75 | 55 | 80 | 65 | 10 | 10 | 5 | 15 | 10 | 20 | 10 | 5 | 5 | 15 |
| Volleyball | 55 | 55 | 70 | 60 | 30 | 25 | 10 | 25 | 10 | 15 | 15 | 10 | 5 | 5 |
| Football | 70 | 50 | 60 | 50 | 20 | 35 | 40 | 35 | 10 | 15 | 0 | 15 | 0 | 0 |
| Handball | 80 | 80 | 75 | 60 | 20 | 20 | 25 | 40 | 0 | 0 | 0 | 0 | 0 | 0 |
| Land hockey | 75 | 55 | 70 | 65 | 15 | 20 | 30 | 15 | 10 | 10 | 0 | 5 | 0 | 15 |
| Rugby | 70 | 70 | 65 | 70 | 10 | 15 | 20 | 20 | 10 | 10 | 5 | 5 | 10 | 5 |
| Water-polo | 50 | 60 | 65 | 60 | 30 | 25 | 25 | 35 | 15 | 10 | 5 | 0 | 5 | 5 |
| Swimming | 80 | 75 | 85 | 85 | 15 | 20 | 15 | 5 | 5 | 5 | 0 | 10 | 0 | 0 |
| Rowing | 75 | 70 | 75 | 75 | 15 | 15 | 15 | 15 | 5 | 5 | 5 | 0 | 5 | 10 |
| Cycling | 85 | 75 | 70 | 55 | 5 | 5 | 20 | 35 | 0 | 0 | 0 | 0 | 10 | 20 |
| Fencing | 80 | 70 | 80 | 80 | 10 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 0 | 0 |
| Modern pentathlon | 70 | 70 | 55 | 70 | 5 | 10 | 35 | 20 | 20 | 15 | 5 | 5 | 5 | 5 |
| Judo | 80 | 70 | 80 | 80 | 5 | 20 | 10 | 10 | 10 | 5 | 5 | 5 | 5 | 5 |
| Athletics-runners 100—200 m | 100 | 90 | 70 | 65 | 0 | 5 | 30 | 30 | 0 | 0 | 0 | 0 | 0 | 5 |
| Athletics-runners 400—1000 m | 60 | 55 | 65 | 50 | 25 | 20 | 30 | 30 | 10 | 15 | 5 | 10 | 5 | 10 |
| Athletics-runners 5 000—10 000 m | 75 | 75 | 65 | 60 | 15 | 10 | 30 | 30 | 10 | 10 | 5 | 5 | 0 | 5 |
| Athletics-Marathon | 70 | 60 | 54 | 40 | 10 | 25 | 35 | 45 | 15 | 15 | 15 | 15 | 5 | 0 |
| Athletics-competitive walking | 80 | 75 | 65 | 50 | 0 | 0 | 20 | 30 | 15 | 15 | 10 | 15 | 5 | 5 |
| Athletics-high jump | 85 | 85 | 80 | 65 | 10 | 5 | 15 | 20 | 5 | 0 | 5 | 5 | 0 | 10 |
| Athletics-long jump | 80 | 80 | 80 | 70 | 15 | 10 | 15 | 25 | 5 | 10 | 5 | 5 | 0 | 0 |
| Athletics-pole vault | 80 | 85 | 85 | 70 | 15 | 5 | 10 | 25 | 0 | 5 | 0 | 0 | 5 | 5 |
| Athletics-discus throwing | 65 | 65 | 60 | 55 | 20 | 15 | 10 | 30 | 15 | 15 | 30 | 10 | 0 | 5 |
| Athletics-javelin throwing | 60 | 70 | 45 | 45 | 25 | 15 | 45 | 35 | 15 | 10 | 10 | 15 | 0 | 5 |
| Weight lifting 60—82.5 kg | 60 | 60 | 60 | 60 | 25 | 20 | 30 | 20 | 15 | 20 | 10 | 20 | 0 | 0 |
| Weight lifting 82.5—90 kg | 40 | 50 | 30 | 30 | 15 | 30 | 60 | 60 | 45 | 20 | 10 | 10 | 0 | 0 |
| Table-tennis | 50 | 70 | 40 | 40 | 30 | 0 | 50 | 40 | 20 | 30 | 10 | 20 | 0 | 0 |
| Tennis | 75 | 85 | 75 | 80 | 15 | 5 | 10 | 10 | 5 | 10 | 10 | 10 | 5 | 0 |
| Skiing, Alpine | 70 | 60 | 40 | 45 | 0 | 0 | 20 | 25 | 30 | 30 | 40 | 20 | 0 | 10 |
| Skiing, cross country | 50 | 70 | 50 | 60 | 20 | 10 | 20 | 10 | 10 | 10 | 10 | 20 | 20 | 10 |
| Figure-skating | 70 | 50 | 50 | 35 | 10 | 20 | 30 | 35 | 20 | 20 | 20 | 20 | 0 | 10 |

highest number of normal foot arch had the women handball players and weight-putters, while the lowest is the representation of kayakers and long jumpers. The interesting thing is that there are no people with flat foot among kayakers, but many of them have slightly flattened feet. From the attached tables follow the results of the intense load on foot formation in various sports and the due conclusions can be deduced from it.

## DISCUSSION

Although foot formation was dealt with by many scientific workers, the first large event focusing on it was the 13th Congress of Sports Medicine (FIMS — Fédération internationale de médicine sportive) in Vienna in the year 1960. Following the report by Govaerts, President of FIMS, dealing with the function of foot from the biochemical point of view (Govaerts A. 1960), many people were concerned with the influence of sporting activities on foot. Their approach, however, differed a great deal, the authors concentrated on a few sports and games only and their results showed also considerable difference. Neither have brought about any new development the recent years. We hold therefore that the results of our research covering almost all sports and games will contribute not only towards solving some of the outstanding problems of sports medicine, but they will serve also the benefit of the general population.

The results presented in the tables and in the pictures of this study cover a relatively extensive field and it would be useful to discuss the effect of every individual sport or game separately. It is possible to deduce the consequences from the positive or negative findings, both for the physical culture, and also for application in the general practice for the non-sporting public and for the patients. The extent of the paper does not provide for far-reaching analyses, it presents the results in certain branches only.

Evidently the judging of the foot according Schwartz angle brings somewhat more negative results than the evaluation with the help of Chippaux index. The first method registers precisely enough the cases where the transverse arch is becoming lower (and this occurs more frequently), while the second method focuses on more evident changes effecting the longitudinal arch. Thus both methods comport to a certain degree with the characteristic of the load on



TABLE 6. *Frequency of various foot formation (in %) in top sportswomen (A — Method of Chippaux, B — Method of Schwartz)*

| Foot arch | Normal | | | | Slightly flattened | | | | Flat | | | | Hight | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Method | A | | B | | A | | B | | A | | B | | | |
| Foct | right | left | right | left | right | left | right | left | right | left | right | left | right | left |
| *Sports Events* | | | | | | | | | | | | | | |
| Volleyball | 80 | 70 | 75 | 70 | 5 | 15 | 20 | 15 | 15 | 5 | 5 | 5 | 0 | 10 |
| Basketball | 70 | 55 | 65 | 55 | 10 | 5 | 25 | 15 | 20 | 20 | 10 | 10 | 0 | 20 |
| Handball | 90 | 90 | 90 | 85 | 5 | 5 | 5 | 10 | 0 | 0 | 0 | 0 | 5 | 5 |
| Football | 65 | 70 | 55 | 65 | 25 | 15 | 30 | 20 | 10 | 15 | 15 | 15 | 0 | 0 |
| Land hockey | 80 | 80 | 80 | 80 | 10 | 0 | 10 | 10 | 10 | 10 | 10 | 0 | 0 | 10 |
| Athletics-runners 100—200 m | 95 | 95 | 75 | 85 | 0 | 5 | 20 | 15 | 5 | 0 | 5 | 0 | 0 | 0 |
| Athletics-runners 400—800 m | 75 | 80 | 60 | 60 | 10 | 10 | 30 | 25 | 10 | 0 | 5 | 5 | 5 | 10 |
| Athletics-runners 1 500 m | 80 | 55 | 60 | 55 | 10 | 25 | 30 | 25 | 10 | 5 | 5 | 5 | 0 | 15 |
| Athletics-high jump | 70 | 70 | 60 | 65 | 20 | 20 | 30 | 25 | 5 | 5 | 5 | 5 | 5 | 5 |
| Athletics-long jump | 75 | 65 | 60 | 50 | 15 | 10 | 25 | 35 | 5 | 20 | 10 | 10 | 5 | 5 |
| Athletics-shot putting | 80 | 95 | 90 | 90 | 15 | 0 | 5 | 10 | 0 | 5 | 0 | 0 | 5 | 0 |
| Gymnastics | 90 | 70 | 85 | 65 | 5 | 5 | 10 | 10 | 0 | 0 | 0 | 0 | 5 | 25 |
| Modern Gymnastics | 80 | 75 | 75 | 55 | 5 | 5 | 10 | 25 | 0 | 0 | 0 | 0 | 15 | 20 |
| Tennis | 85 | 75 | 75 | 70 | 5 | 15 | 10 | 15 | 0 | 0 | 5 | 5 | 10 | 10 |
| Swimming | 90 | 75 | 75 | 60 | 10 | 10 | 25 | 30 | 0 | 10 | 0 | 5 | 0 | 5 |
| Rowing | 70 | 80 | 70 | 70 | 5 | 10 | 10 | 25 | 5 | 5 | 0 | 0 | 20 | 5 |
| Canoeing | 80 | 70 | 55 | 55 | 20 | 20 | 45 | 40 | 0 | 5 | 0 | 0 | 0 | 5 |
| Athletics-pentathlon | 70 | 50 | 70 | 50 | 30 | 20 | 10 | 20 | 0 | 10 | 20 | 10 | 0 | 20 |
| Skiing cross country | 80 | 80 | 60 | 60 | 10 | 20 | 30 | 30 | 10 | 0 | 10 | 10 | 0 | 0 |
| Skiing, Alpine | 90 | 80 | 70 | 50 | 0 | 0 | 20 | 30 | 0 | 10 | 0 | 10 | 10 | 10 |
| Figure-skating | 80 | 85 | 70 | 70 | 0 | 5 | 15 | 25 | 10 | 5 | 5 | 0 | 10 | 5 |
| Fencing | 80 | 80 | 60 | 60 | 20 | 20 | 40 | 30 | 0 | 0 | 0 | 10 | 0 | 0 |
| Judo | 80 | 80 | 60 | 70 | 20 | 20 | 30 | 20 | 0 | 0 | 10 | 10 | 0 | 0 |

foot on practicing a certain sport or game. Thus e.g. cyclists, weight-putters, sprinters or high jumpers show more negative results with angle evaluation than with the evaluation of the index. Of decisive importance is the share of dynamic and static phases during the sporting. The results show that foot formation is better in sports where elastic rebound is required than in sports characterized by frequent falls with full weight on the feet.

The frequent considerations that heavy body weight and larger amount of body fat rank among the main factors causing flat foot (P. Štěpánek, V. Křížek, 1966) prompted the realization of a series of correlations among these body characters. We carried them out on a sample of population aged 25 years and no relations were detected in this direction (V. Novotný 1976). That's why a further study included 5 age categories of men and women. But here too we failed to prove any interdependence between body weight, the amount of body fat or lean body mass on the one side, and between foot formation on the other (V. Novotný, M. Bavor, 1977). No such interdependence was discovered, not even in the group of weight-lifters, known as sportsmen with the lowest foot arch. Their feet did not show any considerable change, not even under the load of 40 kg and 80 kg bar bells. The work by Bavor and all. (1977) brought similar results, refuting the theory that the foot arch can undergo negative changes due to gravidity. The fact that foot formation is not connected with body weight is confirmed also by the present paper. Some heavy sportsmen (e.g. weight-putters, basketball players, swimmers) have excellent foot arch, and on the contrary some sportsmen with smaller body mass (e.g. endurance runners, table-tennis players) have not so favourable foot formation. There are of course cases when heavy weight is combined with considerably flat foot. But it is never due to heavier body weight, it is the consequence of genetic disposition.

Among sportswomen with the best foot formation belong modern gymnasts, as hown in *Figs. 3 and 4.*


FIGURE 3. *Changes in foot formation from 13 to 23 years in Olympic woman-champion in high diving.*

FIGURE 4. *The plantograms are a documentation of foot formation in marathon runners before race.*

At the First World Championship of Modern Gymnastics we had the opportunity to examine in a complex way all participants from 10 countries. The method included also the examination of feet, of great importance for the performance of modern gymnasts. It appeared (A. Martinovská et all., 1968) that none of the participants had flat foot in the sense of longitudinal arch, 9 per cent had their feet slightly lowered, and 91 per cent had normal feet. The evaluation of the transverse arch was also very positive, but the percentage of normal values was smaller. Special attention was focused on the World Champion (V. Novotný, 1968). Her foot formation was perfect in both directions. Thus the earlier results are in accord with the present ones, although the demands in this particular sport have risen considerably.

Diving is not included in the tables for lack of the required number of top acrobatic divers. On jumping off the diving tower they load their feet in a specific way. For this reason the case of a female Olympic Medal winner, whose physical and functional development was systematically followed from *8 to 23 years of age* might be of some interest. The work (V. Novotný 1981) includes even a plantographic and pedobaroscopic follow-up of the development of her feet. The development of feet of this outstanding acrobatic diver is shown in *Figure 3.* It documents the gradual rising of her foot arch — slightly flattened in youth — reaching absolutely normal state.

It is apparent from the results that in the athletic categories sprinters have better foot formation than endurance runners, the foot formation of high jumpers and pole jumpers is more favourable than that of long jumpers; pole jumpers and weight — putters have better foot formation than javelin and discus-throwers. Other authors also arrive in similar conclusions (F. G. Markusas 1961), (G. P. Polianski 1961). But there is also a study ascribing only 20 per cent of normal foot to sprinters (N. N. Priorov et all. 1960). Priorov's study pays attention also to the return of lowered arch following training to the original values. These observations remind also of our paper (V. Novotný, 1968); during the Košice Marathon Race the feet of 109 Marathon runners from 16 countries were measured. According to Chippaux index 55 per cent of the runners had normal feet (45 per cent according to Schwartz angle). The rest had slightly or entirely flat feet. The plantogram of sample of Marathon runners was made immediately following the competition. It appeared that runners with normal feet showed no significant changes on concluding the 42 km race. But the most surprising thing was that those with flat feet showed a statistically significant improvement following the race — see *Figs. 4 and 5.*



Basketball players have the best foot formation among sportsmen engaged in competitive games (C. Nižankowski, A. Vanke, 1961), while volleyball players — both males and females — probably because of the different form of thrusting the feet and landing after the jump foot formation in this sport — occupy a middle position.

Football (soccer) players are ranged to the second-half of the table although the way in which they play and run loads the external side of their feet. A warning voice to this question can be heard already in the first anathomical-orthopedic works concerned with football (K. Hora, 1931). Even table-tennis players belong to those with lower foot arch.

This sport is characterized by continuous quick sallies and the more likely remedy is to use a different type of footwear. Figure skaters and Alpine skiers are also in the second-half of the tables, documenting that they have lower foot arch than is the case with other sports.

On the other hand rowers, both males and females, belong to the first-third of those with very good foot arch. In our previous paper (V. Novotný, 1964), in which we described the results of the examination of the Czechoslovak rowers — 1969 state representatives — we can state that these results were less favourable. The same follows also from other studies (V. Novotný, E. Tamassy, 1967) summarizing the results of the examination of the world's top rowers. Other works of A. Tschagowadse, Z. Placheta, 1965) also indicate that rowers often have lower foot arch. The recent development seems to be positive in this branch. The situation is similar also in the group of cyclists. On examining the competitors of the Prague—Berlin—Warsaw Cycle Race (2559 km) in the year 1963 coming from 18 countries (V. Novotný et all. 1966) it was found out that 30 per cent of the cyclists had flat feet and 38 per cent slightly flat feet. At present the Czechoslovak cyclists rank with sportsmen with very good foot arch.

During the recent 20 years considerable progress has been reached in the preventive-medical care of the sportsmen. The demands for higher output are growing, but at the same time conditions are improving and the negative impacts of the load on the organism are minimalized. Rehabilitation of sportsmen doesn't serve the treatment of damaged organs only, it forms part of the preparation of sportsmen for high performance. The design of special footwear for the individual sports (W. Thomsen, 1961) respects the demands in line with the function of the foot and its specific tasks (J. Klementa, 1971). It is expected that the introduction of improved footwear will have a positive impact on the formation of the feet. At the

FIGURE 5. *The plantograms are a documentation of foot formation in marathon runners after race.*

same time we should bear in mind the fact that a foot arch which seems to be lowered at the first sight need not be a warning symptom; there are known cases of Marathon runners who competed for several decades with slightly or completely flat feet, and were running several thousand kilometres a year without subjective difficulties even after the age of 60 years.

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