DEPENDENCY OF REARFOOT PRONATION ON PHYSICAL STRAIN

L. Thorwesten[1], A. Fromme[1], F. Winkelmann[1], R. Reer[1], J. Jerosch[1,2]

Westfälische Wilhelms-University Münster, Institute of Sports Medicine[1], Department of Orthopaedic Surgery[2], Germany.

INTRODUCTION

Acute and chronic injuries of runners are still a central topic in the field of Sports Medicine. The cause for acute running injuries is relatively easy to determine but the search for reasons regarding running-related chronic sports injuries as runner's knee, shin splint or achillodynia are by far more difficult.

Training parameters, as extent and ground, and anatomical conditions as foot malformations as well are functional criteria which should be taken into consideration when determing the reason for running injuries. The normal pronation has a significant importance with regard to the correct function of the foot (HENNIG 1994, JAMES/BATES/OSTERNIG 1978) but the excessive pronation is considered to be a frequent cause for complaints on one's foot, lower leg and knee (KÄLIN et al. 1988). In order to quantify the degree of the pronation different methods are employed to record different parameters. One important parameter is the angle of the Achilles tendon which is measured as the angle between the lower leg and the heel-bone. Results from gait analyses and examinations with different running speeds exist in order to describe the effect on the angle of the Achilles tendon (MANN/HAGY 1980, NIGG 1986).

During the daily follow-up of runners it can be found quite often that especially at the end of the training session an increased pronation takes place. These findings are in contrast to those in the beginning of the training session where usually no obvious alterations of the pronation angle is detectable. Taking these casuistic observations into account the primary purpose of the following investigation was to examine if the pronation angle is dependent on the physical strain and if a difference between endurance-trained and not endurance-trained runners is detectable.

METHODS

Volunteers: We examined 34 test persons in two groups. The endurance-trained group: (age: 26.5+/-4.7 years, height: 181.7+/-8.7 cm, weight: 70.4+/-8.3 kg, drawn from a group of middle- and long-distance runners of a track and field athletics club). The not endurance-trained group: (age: 23.8+/-3.6 years, height: 180.9+/-7.5 cm, weight: 75.5+/-8.1 kg, recruited from a group of sports students). In order to exclude variations caused by the running style only heel-bone runners were included in the study, and only volunteers who were experienced with the treadmill testing were selected. A regular training frequency of at least 3times a week with a training extent of at least 30 kilometers a week were the selection criteria for the endurance-trained group.

Test setup: We used a Woodway-treadmill with a degree of hardness of 40 shore and a high-frequency measurement system Hentschel 84.330 whose camera was positioned three meters behind the runner at the same height as the surface of the treadmill. The Hentschel High-speed measuring system used for this study records markers which were fixed at the volunteer`s leg, directly on the skin. These markers are low of mass, round (diameter of 6 mm) and they reflect hitting halogen light. The halogen lamps were positioned in a ring-like manner around the objective of the camera (Hamamatsu). The scanner recorded a set number of light dots. For each measuring event a total measuring frequency of 15 kHz at the most could be achieved. At the present study a camera frequency of 7.5 kHz was chosen. This total frequency had to be divided by the number of measuring dots - in this case four - this meant that the motion could be registered by means of a frequency of 1875 Hz.

Test procedure: Each volunteer was questioned by means of a standardised orthopaedic questionnaire in order to rule out anatomically caused malformations. The fixation of the markers was always done at the left leg and was performed according to the test design of STACOFF/KÄLIN/STÜSSI (1991). The pronation angle was determined by means of the node angle calculation of the Hentschel system. The treadmill analysis was carried out barefooted. For the treadmill ergometry we used a standardised setup according to HECK et al. (1982). We carried out a multiple-step test on the treadmill commencing at a speed of 8 km/h. The speed was increased by 2 km/h for each step every 3 minutes until subjective exhaustion. After reaching subjective exhaustion the speed decreased by 8 km/h. The pulse rate was measured and the blood lactate was drawn from the ear lobe.

RESULTS

The differences regarding the heart rate between endurance-trained and not endurance-trained volunteers are clearly recognizable and highly significant up to the 20 km/h step. On given exercise loads the endurance-trained showed substantially lower heart rates as expected. A linear increase with regard to the heart rate can be found within both groups. The heart rate kinetics confirm the findings of the work physiology referring to the stepwise increase of the exercise load during ergometry (Kindermann 1987). The differences regarding the second tested exercise parameter, the lactate concentration, are just as clear.

Absolute pronation angle: For the absolute pronation angle refer to Fig.1. Taking the entire study group into consideration an increase of the pronation angle can be found with increasing running speed up to 16 km/h. At a speed of 18 km/h the mean value declines again. But it has to be considered that the number of volunteers decreased at high speed levels. Only two athletes reached the last two steps. For this reason the mean value will not be discussed in more details. *Alteration of the pronation angle*: The angle alterations were calculated in relation to the pronation angle at a speed of 8 km/h (Fig.2). The alteration of the pronation angle (in relation to an angle at a speed of 8 km/h) for the not enduranced trained group is higher, but the differences between both groups were not significant. *Average pronation angle before and after subjective exhaustion*: After reaching the maximal step the runners

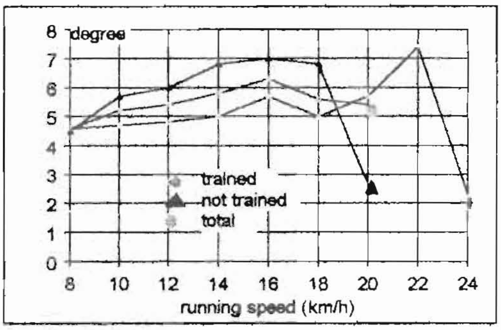

Fig.1: *Absolute pronation angle*

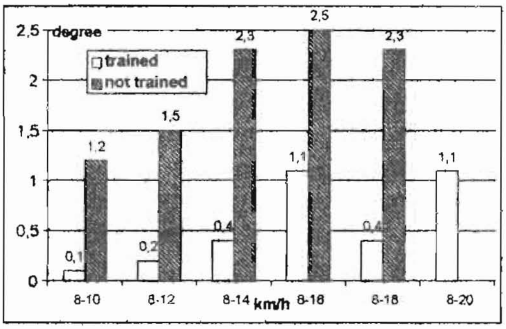

Fig. 2: *Alteration of pronation angle*

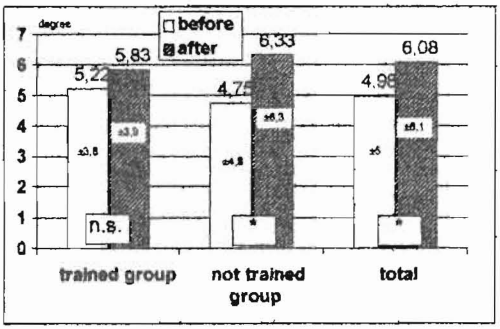

Fig. 3: *Average pronation angle before and after reaching subjective exhaustion at the same individuell speed*

Correlation between pronation angle and lactate conoctration

	km/h	8	10	12	14	16	18	20
trained (ET)	r	0,22	0,21	0,31	0,25	-0,01	-0,25	0,02
	sign.	0,58	0,57	0,34	0,46	0,87	0,52	0,97
not trained (NOT)	r	*0,93*	0,55	*0,81*	*0,95*	*0,83*	*0,7*	-
	sign.	*0,00*	0,12	*0,01*	*0,00*	*0,00*	0,12	-

Tab. 1

performed an additional 3min. run with a velocity reduced by 8 km/h compared to the maximal speed. On this stage the total group showed significantly greater pronation angles compared to those of the corresponding velocity at the beginning of the test (Fig.3). *Lactate and angle of the Achilles tendon*: The average lactate concentration as well as the pronation angle increased up to a velocity of 16 km/h among the entire group. Among the group of the endurance-trained (ET) there is no statistically significant correlation between blood lactate concentration and pronation angle. Among the group of not endurance-trained (NOT), a statistically highly significant correlation between pronation angle and lactate concentration was found for most of the exercise steps. Tab.1 shows the corresponding correlation coefficients.

Discussion

The human foot as a complex biomechanical system has the task to protect the standing position, to serve as a means of locomotion and especially to function as a shock absorber. Because of the special distribution of its bones a significant part of the shock can be absorbed already by means of the longitudinal and horizontal arch respectively. The pronation movement contributes to the shock absorption as well. From the mechanical point of view this fact can be explained by the phenomenon of an extended braking distance by which the braking distance and the braking time during ground contact is lengthened (HENNIG 1986). MANN (1982) confirms this important task of the pronation to absorb those forces which have an effect on the body during ground contact. In this connection SEGESSER (1974) talks about "pronation escape flexion" which is stabilized by means of active elements in a springy manner. Further studies (JAMES/BATES/OSTERNIG 1978; BATES/ OSTERNIG 1979; SEGESSER/ NIGG 1980; SEGESSER/STACOFF 1983; KÄLIN u.a. 1988;) reached in principle the same conclusions but they simultaneously emphasize the danger of an excessive pronation which is also called "overpronation" (HENNIG 1986) or "hyperpronation" and is considered to be one of the main causes for runnig-related complaints.

Skin markers can cause major problems because of skin shifting and the shoe markers because of foot motions within the shoe. When measuring the shoe versus the heel NIGG detected only deviations of 2-3° (NIGG 1986). BRAND (1993), however, could prove significantly greater "shoe angle values" than "foot angle values" which varied between 5° and 17°. Usually the supination-pronation-supination motion is maintained during running as well. With increasing rise of the velocity, however, alterations regarding the running style can occur. Experienced runners change mostly from the initial heel running style towards a middle- or forefoot style. Measurements concerning the pronation angle are published in many different variations. Pronation angles are compared at different degrees of sole hardness, at different heel levels (FREDERICK 1987), and the pronation angle depending on the degree of sole hardness and the running speed was described as well. With reference to that NIGG (1986) stresses that at a sole hardness of 25 shore as well as of 45 shore there is a poorly significant correlation between pronation and speed.

With regard to the influence of footwear compared to running barefooted there is general consent that the running shoe alters the biomechanical aspects of the motion sequences of the foot compared to running barefooted in every case (SEGESSER 1980). Different opinions, however, exist regarding the effect on the pronation angle. NIGG/LÜTHI 1980, NIGG/SEGESSER 1986, STACOFF/KÄLIN/STÜSSI 1991 received greater pronation angles when running with footwear. BRAND (1993) found remarkably lower pronation angles when running barefooted, but these differences disappeared if the pronation angle could be measured directly in the shoe by means of a hole in the heel cap instead of measuring from the outside of the heel cap. The conclusion of these findings is that the shoe and not the heel within the shoe gives way. This concluding remark is in contrast to NIGG who stated that the deviation was merely 1°. BATES et al. (1978) even found in their investigation that when running with fast speed the pronation angle is greater barefooted than with footwear. The running style, however, has different impacts on the pronation angle. CLARKE et al. (1980) demonstrated that middlefoot runners have greater pronation angles than heel runners. Exact data regarding maximal pronation angles are described in a study of KÄLIN et al. (1985). Their findings reveal interindividual variations between 184° and 209°, i.e. a range of scatter of 25°. The intraindividual variations between 7° up to 12° are substantially lower (KÄLIN et al. 1985).

In our study the average pronation angle was 5.7° which does not deviate to a large extent from the findings in the literature. According to SEGESSER und NIGG the pronation of the ankle joint when running barefooted is approximately 7° (SEGESSER/NIGG 1987). BRAND detected values between 5° and 17° as well (BRAND 1993). In accordance with the literature overpronation is responsible for a variety of runner's complaints. There are, however, not many studies available about angle degrees at which a pronation has to be regarded as an overpronation. Only NIGG et al. defined a degree of 12-15° as the wanted value.

Specific studies about the correlation between pronation and exercise have not been carried out up to now. The muscular portion of the joint motion could be considered to be the link between both factors. Indirectly this is explained in the study of SEGESSER/STACOFF/NIGG (1983). The authors demand for the upper and lower ankle joint to improve the quality of the muscular stabilisation of the motion amplitude by means of a consequent foot gymnastics. Levels of the absolute muscle strength of the plantar and dorsal flexors, the supinators and the pronators do not exist but it can be assumed that these muscles are stronger among trained athletes compared to not trained. Furthermore, the running technique plays an important role as well because by changing the running technique an active adaptation to the strain takes place deliberately or involuntarily.

Our results demonstrate that the increase of the pronation angle is a function of the running speed. But there is also an influence of fatigue, which depends neither on the running velocity nor on the lactate levels during exercise. Therefore, further investigations should lay emphasis upon the question which factors are responsible for this effect.

REFRENCES

Bates, B.T., L.R. Osternig, B.R. Mason: Lower extremity function during the support phase of running. In: Asmussen, E., K. Jorgensen (eds.): Biomechanics VI-B. University Park Press Baltimore 1978.

Bates, B.T., L.R. Osternig, B.R. Mason, S.L. James: Functional variability of the lower extremity during the support phase of running. Med. Sci. Sports Exerc. 11 (1979), 328-331.

Brand, S.: Die Fersenbeweglichkeit im Laufschuh bei Mittel- und Langstreckenläufern. Dissertation, Münster 1993.

Clarke, T.E., M.A. Lafortune, K.R. Williams, P.R. Cavanagh: The relationship between center of pressure location and rearfoot movement in distance running. Med. Sci. Sports Exerc. 12 (1980), 92.

Frederick, E.C.: Anforderungen an die Konstruktion von Laufschuhen. In: Segesser, B., W. Pförringer (Hrsg.): Der Schuh im Sport. Perimed, Erlangen 1987.

Heck, H., A. Mader, H. Liesen, W. Hollmann: Vorschlag zur Standardisierung leistungsdiagnostischer Untersuchungen auf dem Laufband. Dtsch. Z. Sportmed. 33 (1982), 304-307.

Hennig, E.M.: Pronation - positiv oder negativ. Condition 17 (1986), 22-23.

Hennig, E.M.: Der Fuß als Stoßdämpfer. Runner's world 2 (1994), 34-39.

James, C., B.T. Bates, L.R. Osternig: Injuries to runners. Am. J. Sports Med. 6 (1978), 40-50.

Kälin, X., E. Unold, E. Stüssi, A. Stacoff: Interindividual and intraindividual variabilities in running. In: Winter, D.A., R.W. Norman, R.P. Wells, K.C. Hages, A.E. Patla (eds.): Biomechanics IX-B. Human Kinetics, Champaign 1985.

Kälin, X., J. Denoth, A. Stacoff, E. Stüssi: Läuferverletzungen und Laufschuhkonstruktion: Darstellung möglicher Zusammenhänge. Sportverl. Sportschad. 2 (1988), 80-85.

Mann, R.A., J.L. Hagy: Running, jogging and walking: A comparative elektromyo-graphic and biomechanical study. In: Batemann, J.E., A.W. Trott (eds.): The foot and ankle. Thieme, Stuttgart/New-York 1980.

Mann, R.A.: Biomechanics of running. In: Mack, R.P. (ed.): The foot and leg in running sports. Mosby, St. Louis 1982.

Nigg, B.M., S. Lüthi: Bewegungsanalysen beim Laufschuh. Sportwissenschaft 10 (1980), 309-320.

Nigg, B.M., B. Segesser: Der Laufschuh - Ein Mittel zur Prävention von Laufbeschwerden. Z. Orthop. 124 (1986), 765-771.

Nigg, B.M.: Biomechanics of running shoes. Human Kinetics, Champaign 1986.

Segesser, B.: Tibiale Schmerzzustände und Achillessehnenentzündungen als Folge statischer Störungen. Ther. Umschau 31 (1974), 256-265.

Segesser, B.: Verletzungsprophylaxe durch geeignetes Sportschuhwerk? In: Cotta, H., H. Krahl, K. Steinbrück (Hrsg.): Die Belastungstoleranz des Bewegungsapparates. Thieme, Stuttgart/New-York 1980.

Segesser, B., B.M. Nigg: Insertionstendinosen am Schienbein, Achillodynie und Überlastungsfolgen am Fuß - Ätiologie, Biomechanik, therapeutische Möglichkeiten. Orthopäde 9 (1980), 207-214.

Segesser, B., B.M. Nigg: Der Einfluß von Boden und Schuh auf die Belastungsintensität im Bereich der Sprunggelenke einschließlich prophylaktischer Maßnahmen. Med. u. Sport 23 (1983), 100-101.

Segesser, B., A. Stacoff, B.M. Nigg: Die Belastbarkeit der Sprunggelenke aus biomechanisch-klinischer Sicht. Med. u. Sport 23 (1983), 9-13.

Stacoff, A., X. Kälin, E. Stüssi: The effects of shoes on the torsion and rearfoot motion in running. Med. Sci. Sports Exerc. 23 (1991), 482-490.