

**MONITORING OF CHANGES IN PLANTAR PRESSURE
DISTRIBUTION OF PREPUBERTAL CHILDREN**

**MONITOROVÁNÍ ZMĚN ROZLOŽENÍ TLAKU NA PLOSCCE NOHY U DĚTÍ
MLADŠÍHO ŠKOLNÍHO VĚKU**

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I agree that results of this thesis can be used upon the wise decision of my supervisor and the director of the department. In case of publication, I will be mentioned as a co-author.

I declare that this thesis is an original work, compiled, researched, and written by myself, with professional supervision of my advisor, Ing Jitka Baďurová.

Zlín, May 27, 2005

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Signature

RESUMÉ

Hlavným zámerom diplomovej práce je sledovanie vplyvu cvičenia svalov nôh na rozloženie tlakov na chodidle nôh u detí mladšieho školského veku. Sleduje aký vplyv má plochonožie a valgozita piet na rozloženie tlakov. Práve plochonožie a valgozita piet patria medzi najrozšírenejšie ochorenia nôh u detí mladšieho školského veku.

Táto práca dokazuje pozitívny vplyv cvičenia na sledované deformity, na princípe prenesenia zaťaženia váhy tela z vnútornej strany chodidla na stranu vonkajšiu.

SUMMARY

The intention of this Master thesis is to monitor the influence of the foot exercise on the changes in plantar pressure distribution of pre-pubertal children. The impact of flat foot and heel valgosity on the pressure distribution is also being monitored in this Master thesis. The heel valgosity and flat foot belong to the most frequent foot illnesses in pre-pubertal age.

The positive impact of exercise on these illnesses which work on the principle of the redistribution of the weight and by that of the pressure distribution of both feet has been proved by this Master thesis.

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INTRODUCTION

The human foot is a very complex organ. There is no other foot even closely like it in all nature. Many scientists believe that human foot is, more than any other, part of us, the one feature that clearly distinguishes us from all other living creatures. It is the only foot in nature with a heel bone that touches the ground, that has a straight-ahead big toe (instead of thumb-like), and that has an arch. These unusual features have enabled us to stand and walk upright on two feet with a stride – a feat never achieved by any other creature (1).

The human foot is unique ever since its development in early childhood. According to the survey on monitoring the foot health status of children at the age of three to fifteen, the beginnings of foot illnesses were registered. Flat feet and valgosity are currently two of the most frequent illnesses associated with children's feet (2). Currently, these illnesses are commonly treated by passively prescribed commercially produced orthopedic inserts (3). This production in fact does not respond to the individual needs of children's feet. Since the inserts only passively support the longitudinal arch, the muscles in the foot get flaccid as a result (1).

The aim of this Master thesis is to prove, by means of monitoring the changes in plantar pressure distribution in children aged 5 to 12, the importance of the exercise and the training of the foot muscles in prevention or correction of the foot illnesses, such as flat foot and valgosity. The children of age five to twelve were chosen because the pre-pubertal development of human foot is considered to play the most important role in the forming of the human foot.

The monitoring of changes in plantar pressure distribution is a very important tool that helps us understand the importance of exercising and activating foot muscles. This is found to be very helpful in avoiding feet related illnesses.

The exercise and the training of the foot muscles may be performed by the professional people, for instance by teachers during Physical Education Classes, or orthopedists during the therapy. But this exercise can be performed even by the nonprofessionals, especially parents, if they follow the guidelines given by the professionals carefully.

THEORY

1.1 Human foot anatomy

Before we start talking about the monitoring of changes in the plantar pressure distribution, it is very important to start with the subject of foot anatomy, the structural design and makeup of the foot. Foot anatomy consists of:

Primary parts: the bones, muscles and tendons, ligaments, joints, arches, nerves and blood system.

Additional parts: the sweat glands, skin and nails (1).

1.1.1 The bones

The foot has 26 bones. Which makes 52 bones for a pair. That's one-fourth of all the 206 bones of the body.

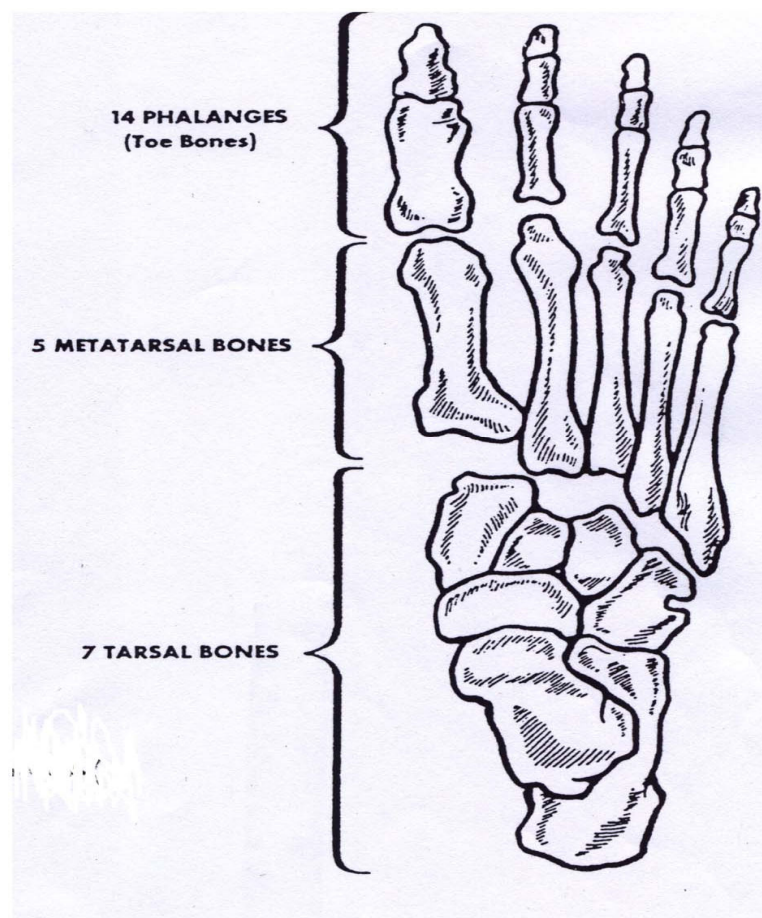


Figure 1. Bones of the foot

Those 26 bones are arranged in three sections: the tarsus with 7 chunky bones form the rear foot. The metatarsus composed of 5 long, thin bones comprises the midfoot and the phalanges which consist of 14 very small bones forming the toes. Each of these sections has its own special design (1).

The tarsus. The tarsus contains the largest bone of the foot, the heel bone (known as the calcaneus, and also sometimes as the os calcis). It is large and chunky because it must bear the initial impact of body weight with each step in walking. It is also a prime stabilizer of body weight and balance in standing. Just above and a bit in front of the heel bone is another very important bone called the talus. The talus is the bone that connects the foot with the bones of the lower leg to help form the ankle joint. The five other bones of the tarsus are a bit smaller, but are also thickest. All seven bones of the tarsus have a similar squat-like design and together are a compact unit that forms the skeletal rear foot.

Metatarsus. This consists of five long, finger-like bones, each called a metatarsal, and together which form the skeletal midfoot joining the tarsus to the rear and the toe bones in front. Each metatarsal bone consists of a head in front, a shaft in the middle, a base at the rear (4).

Phalanges. There are 14 of these toe bones. The big toe has two, while each of the other toes has three. The big toe bones are relatively large because the big toe itself is the workhorse of the toe group and thereby needs more size and strength.

Sesamoid bones. These are two “extra” bones of the foot. If we include them to the total count, then each foot has actually 28 rather than 26 bones. They are pea-sized bones situated on the under surface of the big toe joint, under the metatarsal head (4).

1.1.2 Muscles and tendons

The foot has 19 muscles and tendons, 18 of which are on the sole of the foot. In addition there are 13 leg muscles whose extended tendons are attached to different places in the foot. No two muscles of the body, or of the foot or leg, are exactly alike. Each is specialized for a particular function. There is a difference between a muscle and a tendon. The muscle itself is the main part, the body of the tissue. The tendon consists of the ends of the muscle. The tendon is the portion that connects the muscle to the bone.

The function of the muscle is to move the body and its parts. All the foot and leg muscles are “voluntary”, which means that they work when you decide. There are also “involuntary” muscles, such as the heart or the breathing muscles, that work automatically.

Muscles are composed of elastic fibers which give them their natural stretch-and-contract ability. Tendons are only partly elastic. Most muscles work in pairs. When one flexes or contracts, the other extends, or stretches. The stretch muscles are called extensors, and the contraction muscles are called flexors. The interplay between muscle extension and flexion is responsible for all motions of the body.

The Achilles tendon behind the heel is the largest and most powerful tendon in the body. It is formed by large calf muscles which taper down to become the Achilles tendon, which is attached to the back of the heel bone (1).

1.1.3 The ligaments

The foot has 107 ligaments. The ligaments are the powerful bands that hold the foot's many joints together and help to maintain it as an intact and functional unit against all stresses. A ligament is composed of tough, gristle-like cartilage made up of strands of strong fibers. Ligaments do not have the elastic, resilient quality of muscles, but they do have a small amount of yield ability for some degree of stretching and contracting.

The function of ligaments is to hold the joint intact together – to allow just enough joint motion to provide necessary joint action.

The largest and the most important ligament of the foot is called the “plantar fascia.” It serves to hold the whole bottom area of the foot intact as a unit (3).

1.1.4 The nerves and blood vessels

The nerves of the foot serve as sensors, the electrical impulses system by which we feel and automatically respond to sensations like pain or heat. They are also stimulators that motivate function of the body's parts, including muscles.

The blood system consists of three types of vessels: arteries which carry fresh blood from the heart to the foot, veins which carry the blood back to the heart, and capillaries, which are tiny vessels branching out from arteries and veins to reach into the outpost and surface areas of the foot (4).

1.1.5 The joints

A joint is the site where two or more bones butt together. The foot has many joints – 38. The ankle is the largest and the most important joint of the foot. It is formed by the bottom portions of the two leg bones (tibia and fibula) and the upper part of the foot's talus

bone just above the heel bone. The convexly curved surface of the talus fits into the socket-like pocket formed by the lower ends of the leg bones.

There is a lubricating substance called “synovial fluid” inside the joint. It prevents the wear and tear, of bones, rubbing against each other.

The joints are important for retaining normal foot alignment and function. When one or more joints go out of normal alignment, problems can occur. Examples are crooked big toes (hallux valgus), or a fallen arch. One joint displacement, especially in the tarsus or metatarsus, affects the alignment of the other surrounding joints (4).

1.1.6 The arches

The human foot is the only one with an arch – the long arch along the inner border, known as the inner longitudinal arch. It extends from the front of the heel bone to the base of the first metatarsal bone just behind the great toe joint. There is no “normal” height to this arch. It can be high, medium, low, or even flat and still be structurally normal.

The metatarsal arch is the slightly dome shaped curve formed by the five metatarsal heads across the ball of the foot. When the foot is at rest, there is normally a dome-shaped curvature of the top of the ball. However, when a foot bears weight, this arch normally flattens.

The outer longitudinal arch. With the foot at rest there is a slight arch along the outer border from the front of the heel bone to the head of the 5th metatarsal bone.

The transverse arch is one that is not seen, because it is inside of the foot, a slightly domed area going side to side inside the tarsal area, just behind the instep.

The arch serves primarily as a shock absorber in standing, walking, running, etc. Without the arch, the foot would have less resiliency, and the foot would be less able to absorb “step shocks.” The arch is supported by the combination of muscles and ligaments (1, 3, 4, 5, 6).

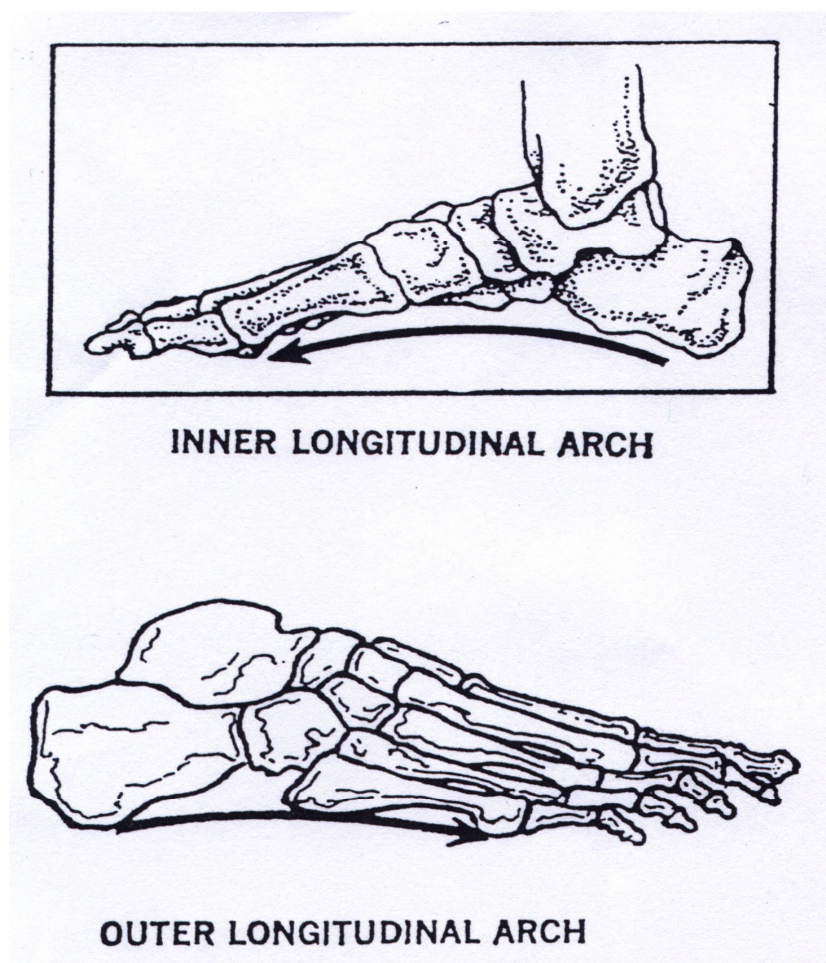


Figure 2. The arches of the foot

1.1.7 Sweat glands, skin, nails

The foot, especially the sole, is richly endowed with sweat glands. A sweat gland is a tightly coiled little tube buried inside the skin and leading to the surface to tiny holes called pores. A pair of average adult feet on an average day gives off a half liter of perspiration. On humid or warm days, or with much foot activity, double of that amount can be given off.

The skin is obviously a very important part of the foot. In fact, many of the foot problems are skin problems (corns, blisters, etc.). Skin is composed of two main layers – the top layer called the “epidermis” and the deeper, thicker layer called the “dermis.” The epidermis is constantly “shedding” and renewing itself with new cells, but the dermis beneath remains essentially intact. The skin on the sole of the foot is 10 times thicker than

found anywhere else on the body. Aside from holding the body together in one piece, its primary function is to serve as an auxiliary breathing apparatus. It helps to maintain normal body temperature. In warm weather the pores open wide to give off perspiration to cool the body. In cold weather the pores become smaller to conserve heat. The skin, via its sweat glands and pores, also helps to pass of the body wastes (1, 4, 5).

1.2 Child foot

The principles of foot anatomy are the same for children and infants as for adults. However, the feet of juveniles have some very special anatomical characteristics because these feet are in a constant state of growth and change. These changes result in some structural differences in the child's foot (1, 3, 4).

1.2.1 Development of the infant foot

A baby's foot is extremely fragile. It is more flesh and cartilage than bone. At this early stage the bones of the foot are more gristle-like cartilage than bone. There are wide spaces between the bones and therefore no joints in the infant foot. It takes about 18 years to grow the foot.

Babies are born with a thick pad of fat under the foot, called the *fat pad*. Sometimes this conceals the arch, giving the impression of a flat foot. But sometimes the arch is quite visible. Most important is that the beginning bone structure of the baby's foot clearly reveals the arch design. The underfoot fat pad soon disappears to make the arch visible.

The toes on a baby's foot are longer than those on an adult foot. They have enormous grip power – 10 to 15 times greater than adult toes relative to foot size. The tiny toes are constantly wiggling, which is nature's way of exercising the foot for development. Toe gripping is also essential for gait balance when the infant starts to walk.

During the first three years, the infant foot grows faster than at any other time in life. Between the first and third year the average baby foot will grow about 2.5 full shoe sizes. By age 2.5 the length of the infant foot will be almost exactly half its ultimate adult length. Thus at age 2.5 it can be predicted with fair accuracy the final size of that foot in adulthood.

At about 28 weeks the baby can sit up with support. At about 40 weeks it starts to creep and crawl. At 11 to 12 months it can pull itself up to standing position, such as in a playpen. Between 13 and 14 months it begins to walk unassisted. The fit and design of the

shoe during first three years are more important than at any other time of life. That's because of the fragile nature of the infant foot – plus the constant activity of the toes within the shoe (1, 4).

1.2.2 Development of children's feet

Between the 4th and 13th year the child's natural foot growth is accompanied by the progressive solidifying. The bones become harder and larger and their ends reach out toward other bones to form their respective joints. The muscles and tendons are acquiring strength through the natural vigorous activity of the child's foot, and the arch is taking firmer shape. By about age 13 the bones and joints have pretty much completed their ossifying (1, 3, 4).

By age 7-8 for girls and age 9 for boys, the foot reaches 75 percent of its ultimate adult size. And by age 11-12 for girls and age 14 for boys the foot will have reached 90 percent of its final adult size. By about age 18 the size and shape of the juvenile foot is just about completed. It is very important to understand that children's feet do not grow at a steady, even pace. Spurt growth is more common than steady growth. A child's foot may show virtually no growth for a year, and then suddenly grow three full shoe sizes over the next year. Throughout this long time of juvenile foot growth and development, these feet are subjected to enormous stresses not experienced by the average adult foot.

There are two especially important features about the child's foot that distinguish it from the adult foot: (1) children's feet are in a constant process of growth and solidifying formation; (2) children's feet are subjected to enormously greater traumatic stresses than adult's feet (1, 3).

1.3 Foot dynamics

Foot anatomy deals with the structural or static foot, while the foot dynamics deals with the functional foot – its movement and actions, its mechanics, and how it copes with the day-to-day stresses imposed on it.

1.3.1 The foot's sections

Orthopedists divide the skeletal foot into two sections: rearfoot and forefoot. The rearfoot consists of the heel bone (calcaneus) and the big talus bone just above it. All the rest is considered the forefoot. More relevant to understanding the functional nature of the

foot is to divide the foot into three sections: rearfoot (the tarsus), midfoot (metatarsus), and toes (phalanges). This attitude is very important, because each of these three sections has its own unique architecture of bones, joints, muscles, tendons and ligaments, and each section has its own special functional character and its own specialized functions (1).

The 7 tarsal or rearfoot bones are chunky and tightly packed together. The joints are close-knit to allow for only minimal movement or spread between them. This is because the tarsus bears the brunt of the body weight and shock impacts in walking. The tarsus has to be very strong to absorb this trauma before transmitting the weight stresses forward. It is the stabilizer for the whole foot. To fulfill these vital functions, the bones of the tarsus must be relatively large and strong, and the joints must be compact. This is also the reason for the complex network of powerful, criss-crossing ligaments that further strengthen the stability of the tarsus for rearfoot control (1, 4).

The metatarsus is designed for resilience and shock absorption. It is designed of 5 long, finger-like metatarsal bones with spaces between the shafts of these bones. Its purpose is to absorb shock and to transport the weight and energy stresses forward along the step paths of the foot. The metatarsus is a kind of flexible bridge across which the weight and stresses are transported to the forefoot in preparation for the step push-off (1, 4).

The phalanges or toes, with their 14 tiny bones, have their own unique design as a unit. They are used to help maintain foot balance, and also some action to contribute to step push-off in walking and running. The big toe is the most important and is vital to the foot's forward thrust in walking and running (1, 4).

The different architectures of the foot's three sections were designed that way for a purpose. Each section has its own specialized function unlike any of the others. Together they form a functional unit of high efficiency to perform many dynamic tasks for which the foot is responsible (1, 4).

1.3.2 The foot's motions

The foot has four motions: extension, flexion, inversion and eversion. Extension is the forward-downward stretch of the foot, such as sitting cross-legged and pointing the toes of the crossed leg downward (plantar-flexion). Flexion is the backward-upward contraction of the foot, such as pointing the toes and the foot toward the leg (dorsi-flexion). Inversion is turning inward of the foot as though trying to face the long arch in the direction

of the other foot. With this motion, the forefoot is also turned inward. Eversion is turning the foot outward by lifting its outer edge off the ground, with the inner arch facing downward (also called abduction).

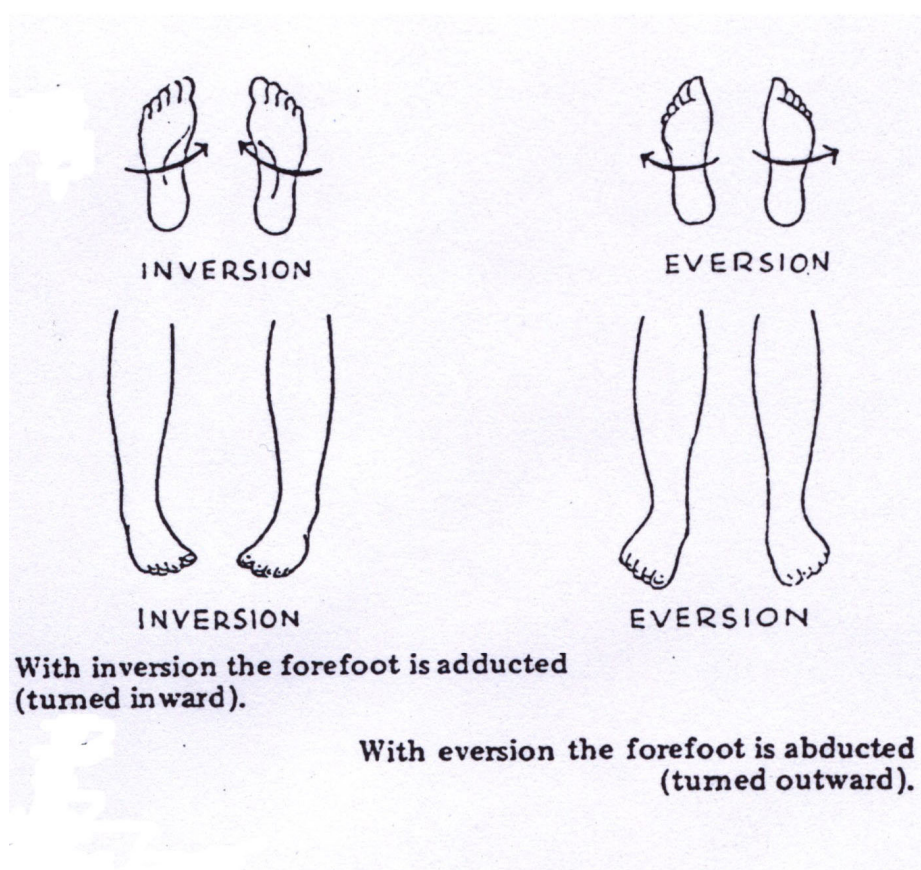


Figure 3. The foot's motions

Extension and flexion of the foot get their movement from the ankle joint. Inversion and eversion get most of their movement from under the ankle joint between the calcaneus and talus. The quality or the agility of these four motions is important indication of the foot's functional health. When any of these motions is diminished from the norm, the foot is unable to function with full mobility. This can be a serious handicap sports or other physical activities. Limited foot motions can also affect the manner of gait or tread pattern. Special exercises are helpful in improving limited foot movements (1, 3, 4).

1.3.3 The foot on weight bearing

The weight bearing foot is quite different from the static or at rest foot. It is a different foot in size, shape and proportions. By weight bearing is meant the foot on standing, but not the walking or running foot. On weight bearing, the foot becomes longer not only forward, but rearward as well. Further, the foot becomes wider across the ball. There is more spread of volume at the waist and instep. The heel is wider, the arch lower.

The diagrams usually show weight bearing on the foot at three places: heel, and under the big toe joint and outer ball joint, forming a neat tripod. Tests show that normally on standing, about 40 per cent of the weight is borne by the rearfoot, about 40 per cent on the ball, and about 20 per cent along the outer border of the foot, mainly around the base of the fifth metatarsal bone (1, 3, 4)

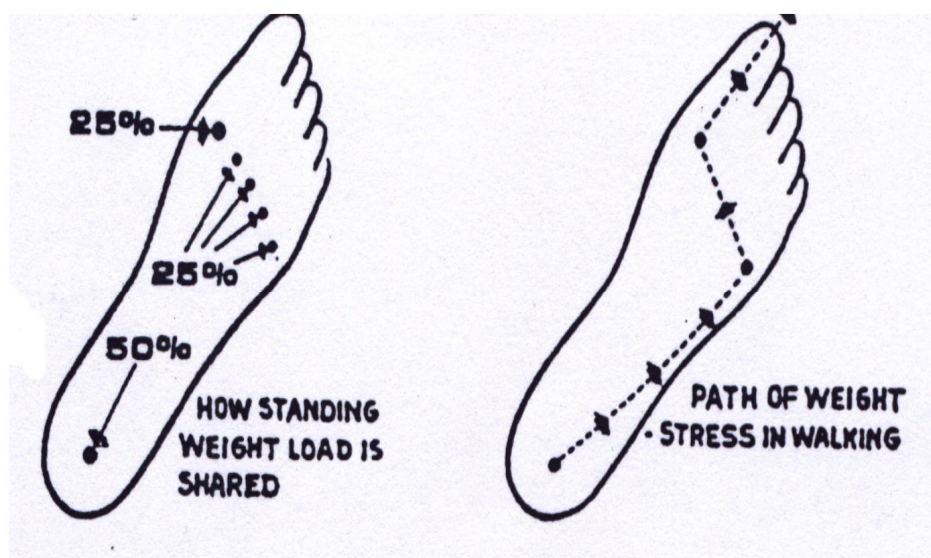


Figure 4. Weight load stresses

The shoe can influence weight bearing ratios on the foot. For instance, a woman standing on high heels imposes 80 per cent or more of her weight on the ball of the foot, with more than average spread across the ball.

Foot balance bears an important influence on how weight and stresses are distributed over the foot on weight bearing. Many people have what is known as foot imbalance. This varies in degree or severity. It means that as a result of some foot fault

there is some shift in the normal pattern of weight and stress distribution over the foot. Some people bear excessive weight on the inner ball of the foot. This can be seen by examining the wear pattern of the old shoe, which will usually show visibly greater wear on the sole at that point. This means that this part of the foot is bearing an excessive wear load while other parts of the foot are not carrying their share of the weight. Such feet usually experience some discomfort and not uncommonly develop some kind of more serious foot disorder. Medical attention can usually restore a normal foot balance with corrected distribution of weight and stress on the foot via the use of orthopedic inserts (1, 3, 4).

1.3.4 Biomechanics of the walking foot

According to the scientists, our manner of walking is the most complex function of the human body. This is indicated by the fact that half of all body's 650 muscles are involved in simple act of walking which demonstrates the muscular coordination required. The term "biomechanics" means the application of the principles of mechanics or dynamics to a living creature or organic part. In our case, we are referring to the dynamics of the walking foot (7).

Walking is a constant body balancing act. Walking is a repeated process of falling-forward and then instantly catching oneself by pushing one leg in front to support and balance that falling-forward body. According to the gait laboratory studies using sophisticated electronic devices and computers, the average person walking at a moderate pace in a low-heel shoe will show the following weight stress distribution path through the foot:

- 1) Heel strike.
- 2) Weight path to the outer border of the midfoot.
- 3) Weight path shifts abruptly to the center of the midfoot.
- 4) Weight thrust moves forward onto the center of the ball.
- 5) Step thrust-off from the center of the ball, the big toe joint and the big toe as a combined unit.

Most of the muscular and leverage power comes from the leg muscles and especially the vital Achilles tendon which is attached to the heel bone. On weight bearing that tendon can exert an upward pull force of one-half ton. The tendon is what provides almost all of

the leverage. If that tendon were severed, the individual would be unable to stand, walk or run.

Foot stances. It has long been a popular notion that the normal stance of the feet in walking is with the feet parallel and toes pointed straight ahead. Studies show that more than 80 per cent of all people walk with a mild degree of out-toeing. Only about 15 per cent walk with feet precisely parallel and toes straight ahead. And only about 2 per cent of adults walk with an in-toeing gait (1, 7).

The toes normally play an active role in walking. It can be seen or experienced by walking barefoot on the grass. The toes instinctively grasp the ground, contributing not only to step propulsion, but to foot balance.

According to the findings of gait biomechanics in foot stress pressure, when walking (or running) person weighs more than his actual body weight is. For example, a person registering 80 kilos of dead weight when standing will apply about 20 per cent more, or a total of 96 kilos of weight on the foot when walking at a moderate pace. The extra weight is called the stress pressure. Weight is simply the amount of the resistance or upward push from the ground required to equalize the downward gravity force of one's body. When the two are equalized, then one has his dead weight. But while walking, one has to impose extra downward pressure on one's feet to get propulsion, to move one's body forward to the next step. Also, all that increased body weight is not shared by two feet, but by one foot at a time. That weight is not distributed over the whole foot, but is concentrated at just very small areas. Walking also creates something called step shock. It is the impact of the foot against hard ground surfaces with each step. As shown in gait laboratory tests, with the heel impact of each step a shockwave instantly travels up the whole body (1, 7).

1.3.5 Biomechanics of the running foot

The biomechanics of the running foot are different from those of walking foot and certainly different from those of the static or weight bearing foot. Here the dynamics become more stressful and rigorous, and the foot itself subjected to many more traumatic forces.

The dynamics of the running foot are in many ways complex. There are many different styles of running, each involving the foot in a different way. The functional stresses on the foot differ in each case (1).

1.4 Foot deformities

The human foot is a complex and sensitive structure which is used for weight bearing, propulsion and shock absorbing. The healthy foot, like the healthy body, needs proper nutrition, care and environment to perform these functions. Any alteration in the function of the foot causes changes in normal gait patterns and abnormal stress concentration. Foot disorders are caused mainly by biomechanical factors, infection and systemic diseases. However, the biomechanical basis of foot disorders is reported to be the most common problem in young people. The biomechanical basis of foot disorders is usually associated with low back pain, leg pain, abnormal weight distribution and abnormal gait (1, 7, 8, 9).

The term deformity means a simple shift from a normal shape based on a defect of the skeleton, ligaments or muscles. The deformities according to the origin are divided to the acquired and the congenital deformities (1, 3, 7, 8, 9).

Foot deformities can be divided to:

- congenital and acquired deformities of the foot (flat foot)
- congenital and acquired deformities of toes (claw toes, bunions, hammer toes)
- skin and nails deformities (calluses, corns, ingrown toe nails)

1.5 Flat foot

Flat foot is often a complex disorder, with diverse symptoms and varying degrees of deformity and disability. There are several types of flat foot, all of which have one characteristic in common - partial or total collapse (loss) of the arch. Other characteristics shared by most types of flat foot include:

- 1 "Toe drift," where the toes and front part of the foot point outward
- 2 The heel tilts toward the outside and the ankle appears to turn in.
- 3 A short Achilles tendon, which causes the heel to lift off the ground earlier when walking and may act as a deforming force (10).

Flat foot is a lay term which describes the appearance of the foot in a pes planovalgus position. Pes planovalgus is a structural deformity which may arise from several causes. Typical of the condition is the outward rotation of the calcaneus with regard to the weight-bearing line of the leg. Associated with this valgus deformity of the heel is a pronation deformity which causes the head of the talus and the navicular and the first cuneiform

bones to be displaced medially and downward. This results in a lowering of the medial longitudinal arch. The anterior part of the foot is not only pronated, but also abducted. The foot is thus in an everted position (7, 11, 12).

This deformity may be congenital or may be acquired. The acquired form may develop as a result of a functional decompensation of the foot, as a result of trauma or secondary to paralysis. Thus pes planovalgus can be classified on an etiologic basis as congenital, static, traumatic, or as paralytic (9, 7, 11).

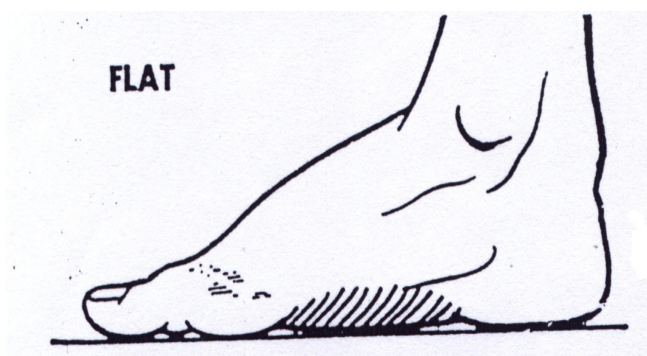


Figure 5. Flat foot

Flat foot can be classified in several classes:

1. Class – the lowering of the medial longitudinal arch is the result of weight bearing, while relieving the foot makes the arch straighten
2. Class - the lowering of the medial longitudinal arch is the result of weight bearing, the lowering of the arch persists while relieving the foot
3. Class – the medial edge of the foot is convex

The classification may be made according to the sole prints, or on special equipment called podometer, which enables to see the standing foot on a board made out of a glass (1, 7, 11, 12).

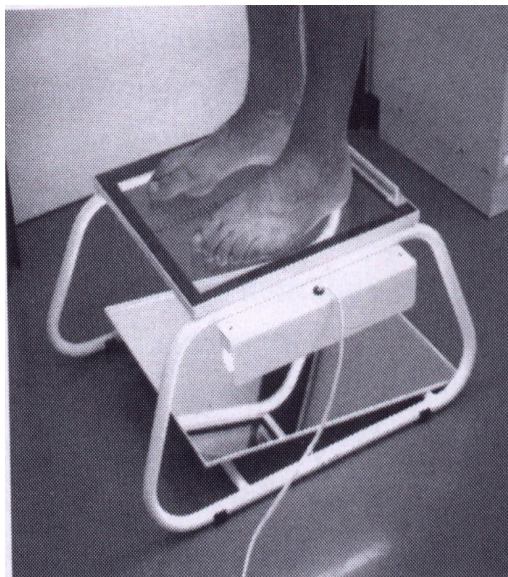


Figure 6. Podometer

1.5.1 Flat foot in childhood

Flat foot frequently occurs in childhood as a result of retardation of development, but more often is the result of a decompensation in function. In early childhood the factors that bring about such a decompensation are primarily the underdeveloped structures. For the most part, the skeleton is still in cartilage. The muscles and ligaments are too weak to hold the normal position on weight bearing. The development of these structures occurs from the time the infant starts to kick and continues through the crawling stage until the first steps are taken. If for some reason the normal use of the limbs in simple kicking and crawling is not permitted, the development of the structures will be hindered. Such a delay in the development of the structures will be a factor in causing pes planovalgus. If the child is encouraged or forced to stand and walk before the structures are ready, the overload on the underdeveloped structures will encourage pes planovalgus. A nutritional disturbance will act as another causative factor (7).

The foot normally shows loss of arch during the stage of first weight bearing. It is not wise to combat this normal position of the foot by the use of support, since such supportive measures will interfere with development and be a causative factor in establishing a true pes planovalgus. Shoes can further be a factor in the condition, if they are too tight, since the toes may be so cramped as to prevent normal development.

Infectious diseases are a causative factor in a static flat foot, because there are more structural weaknesses in these and similar illnesses (1, 7, 11).

1.5.2 Symptoms of the flat foot in childhood

The symptoms of the flat foot in childhood are delayed walking, lack of desire to walk, and fatigue. Pain may be present in the leg and cause a limp. The pain may be in the foot, knee or, occasionally, in the hip. Muscle cramps in the legs may awaken the child during the night. There is interference with the child's ability to play. If walking is forced, the limp becomes more noticeable.

If the condition is not of long standing, the child has an almost instinctive tendency to correct the deformity. This is done by rotating the foot inwardly and by bringing the anterior part of it into adduction with a tendency toward a rolling type of gate. The occurrence of this intoeing in the presence of the foot that shows some valgus and pronation must be interpreted as a natural attempt at correction; it will disappear on treatment of the flat foot (7).

1.5.3 Treatment of the flat foot

There is no treatment until the age of three, because until this time the foot of the child is filled with the fat pad. The regular shape of the foot is developing in the age of three (12).

Prophylactic treatment consists primarily in promoting the normal development of the foot. Any shoe that interferes with this development is contraindicated. In the summer, the child should be permitted to go barefoot on soft ground, lawns, beaches. If desirable, the child may also go barefoot on the rugs indoors (7, 9).

The prevention is very important. Child is not forced or encouraged to stand and walk, until the development of the structures. The proper shoe for children has to be wide in toe and it can not prevent the motion. The correction of the overweight is desirable. It is important to realize that sometimes the correction of the flat foot is made naturally, while growth. The exercise of the short muscles of the foot is very important. The use of artificial exercises, such as picking up marbles with the toes has been found practical. Walking barefoot on the soft ground is suitable (9, 11).

Flat foot of the third class is treated with the use of an insert, which encourages the foot to the normal gait with the foot in the proper position to assure the correct development of the foot (12).

Operative procedures are only rarely considered necessary in children. Operations for the treatment are transplantations of muscles, operations on ligaments, including periosteal grafts and operations on bone, particularly fusions and osteotomies. Operations on the muscles alone, without correction of the foot, are rarely satisfactory (7).

1.5.4 Preventive and corrective exercises

With the corrective exercise, the prevention of the foot deformities is being made. It is very important that the exercise is made correctly and often. The suggestion is to exercise two times daily, at least 20 minutes (13, 14).

Trying to stretch muscles that have not been warmed, is like trying to stretch old, dry rubber bands, they may snap. Warming up prior to stretching does a number of beneficial things, but primarily its purpose is to prepare the body and mind for more strenuous activity. One of the ways it achieves this is by helping to increase the body's core temperature while also increasing the body's muscle temperature. By increasing muscle temperature it helps to make the muscles loose and pliable. This is essential to ensure the maximum benefit is gained from the stretching (13, 14, 15).

The correct warm-up also has the effect of increasing both the heart rate and the respiratory rate. This increases blood flow, which in turn increases the delivery of oxygen and nutrients to the working muscles. All this helps to prepare the muscles and tendons for stretching.

When stretching, it's vitally important that the attention is paid to all the major muscle groups in the body. Just because the particular sport may place a lot of emphasis on the legs, for example, does not mean that it can neglect the muscles of the upper body in the stretching routine. All the muscles play an important part in any physical activity, not just a select few (15).

Every muscle in the body has an opposing muscle that acts against it. For example, the muscles in the front of the leg are opposed by the muscles in the back of the leg. These two groups of muscles provide a resistance to each other to balance the body. If one of

these groups of muscles becomes stronger or more flexible than the opposing group, it is likely to lead to imbalances that can result in injury or postural problems. They are often caused by strong quadriceps and weak, inflexible hamstrings. This imbalance puts a great deal of pressure on the hamstrings and usually results in a muscle tear (15).

We can exercise with a relatively young child. We can let him show us how big he is, but be careful with the correct standing. This is to strengthen his heel. Or child can lie on his back with his feet in the air and turn them up and down in the joint like waving. Then he can be taught to move his feet around in the air, like biking. Then he can move his toes around in the air. Child can be taught to walk on his toes, while for instance listening to the music. He thinks you are playing.

The second set of exercises is picking up the marbles with the toes from the ground. Child may sit on a chair and pretend or actually pick small balls up off the ground and throw them in front of the chair. It is not only small balls, but it can be a piece of a string, or small toys. Be careful with the edges of such small things. Don't let the child pick up dangerous things with sharp edges.

These exercises are performed couple times, not to make child fatigue. And last, but not at least, it is recommended to perform a massage of child's feet after the exercise. This strengthens child's muscles and congests the feet, which leads to relieve (13, 14).

1.6 The in-shoe dynamic pressure measuring system (PEDAR[®] by the Novel GmbH Company in Munich)

The PEDAR[®] system is a reliable pressure distribution measuring system for monitoring local loads between the foot and the shoe. The PEDAR[®] offers versatility with its multiple standard features and operating modes. The PEDAR[®] can be tethered to a PC via a fiber optic USB cable. It can function in a mobile capacity with its built-in Bluetooth[™] technology that is able to communicate with Bluetooth[™] compatible pocket, notebook, or standard PC's. As another alternative, the Pedar has a built-in flash memory storage allowing data to be collected anywhere and later downloaded to the computer.

Due to these features, all testing needs such as walking, running, climbing stairs, carrying loads, playing soccer, or even riding a bicycle can be easily met.

The PEDAR[®] system gets connected to the elastic sensor insoles that cover the whole plantar surface of the foot or sensor pads for the dorsal, medial or lateral areas of the

foot. This system allows multiple synchronization options to use with EMG and video systems for gait analysis.

PEDAR[®] system can be used for all kinds of shoe research. Especially in biomechanics it is indispensable to measure the pressure distribution inside the shoes during the dynamic event. The sensors can be placed on many locations inside the shoe to cover all contacts between the foot and the shoe.

1.6.1 Applications and features of the PEDAR[®] system

PEDAR[®] system can be used in:

- shoe research and design
- ➤ aid in orthotic design
- ➤ rehabilitation assessment
- ➤ kinetic analysis of free gait
- ➤ long term load monitoring
- ➤ sport biomechanics
- ➤ biofeedback

Features of pedar :

- ➤ individual sensor selection
- ➤ online and off-line modes
- ➤ online 2D or 3D display
- ➤ isobar and numeric displays
- ➤ animation of foot contact phases
- ➤ maximum pressure picture (MPP)
- ➤ step selection
- ➤ step timing analysis
- ➤ comparison picture
- ➤ averaged and individual gait lines
- ➤ ASCII output
- ➤ long term body load analysis
- ➤ links to Novel database and Novel scientific software
- ➤ automatic data exchange between PDA and PC

2 AIMS OF THIS THESIS

The flat foot and valgosity are two of the most occurring foot illnesses among children between ages 5 to 12. However, when children get older get, these illnesses have a tendency to occur less-some children may simply outgrow .them in puberty as they do many other childhood illnesses.

The aim of this thesis is to focus on the importance of the exercise and the training of the foot muscles in prevention or correction of the feet illnesses, such as flat feet and valgosity.

There was a couple of goals defined to achieve this:

1. Aim:

Re-measure children (ages 10 to 13) after a year not exercising. These children were measured last year, then there was an exercise being made with them and after 3 months they were re-measured. One of our goals is to re-measure these children again and analyze what happened in a year (while they were not exercising).

Use podometer to view their footprints, take pictures to analyze their feet. Measure their weight, size of the foot and their height.

Use PEDAR[®] Online equipment to record the plantar pressure distribution pattern.

2. Aim:

Measure children between ages 5 to 10. Use podometer to view their footprints, take pictures to analyze their feet. Measure their weight, size of the foot and their height.

Use PEDAR[®] Online equipment to record the plantar pressure distribution pattern.

Teach children to acquire desired exercises.

Re-measure children after 3 months exercising. Use PEDAR[®] Online equipment to record the plantar pressure distribution pattern. Take pictures of children while standing on the podometer.

3. Aim:

Using the Novel software divide the measuring insole into 5 pieces. Create required masks for each insole especially for left and right foot.

Analyze the plantar pressure distribution diagrams in masks for children with valgosity and flat foot and the other children.

Compare the plantar pressure distribution diagrams in each part of the mask among children with valgosity and flat foot and the other children.

Compare the development of the plantar pressure distribution before and after the exercise. Analyze the distribution and come to a conclusion whether there was any change in the pattern of the distribution, meaning if the pressure distribution transferred from the outer to the inner part of the foot.

3 EXPERIMENTAL PART

The changes of plantar pressure distribution (redistributing it from the inner to the outer part of the foot), the effects of exercising on feet and its effects on improving the feet deformities (valgosity and flat foot) in children aged 5 to 12, were observed and evaluated in this experiment.

3.1 Description of the measurement conditions

Children ages 5 to 9 and ages 10 to 13 were chosen for the purpose of monitoring of the changes in plantar pressure distribution of pre-pubertal children. This choice has been made upon the assumption that these children were already without the thick pad of fat, a typical sign of early childhood foot. The other reason was that it was assumed that the positive changes with younger children were more probable to achieve.

Together 94 children, aged 10 to 13, were measured at Slovenská Elementary school in January 2004. 35 children were found with either the flat foot or valgosity or both. One year ago, these 35 children were taught simple exercises to activate their muscles. They exercised 2 times a week under the professional supervision. The re-measurement of these children was performed at the beginning of April 2004. 70 out of 94 children were re-measured again in January 2005. There were 20 children with the flat foot or valgosity.

Second group of 11 children aged 5 to 9 was measured in December 2004 in Hvozdná Elementary school under the same conditions. These children were taught exercises to activate their muscles. However, not only foot muscles, but all postural muscles with the aim to improve their gait and posture. These exercises were mostly performed at home under the parents' supervision for 3 and half months. At the beginning of each month, they were instructed how to perform the exercises by the professional. The final measurement was performed in March 2005.

3.1.1 Simple description of the exercises

1. month exercises:

- Stretching of the calf muscle: a child lies on the tummy, the knee is bent. An adult holds the child's foot and presses toes downward. (30 second interval, should not hurt)

- Stretching of the short muscles of the foot: a child lies on the tummy, the knee is bent. An adult holds the child's heel with one hand, and the other one holds the child's toes. Both hands stretch the child's foot by making an arch movement.
2. month exercises:
- Stabilization of the lower back: let child crawl by playing certain games, for example playing the dog. While crawling, the child stabilizes his lower back and surrounding muscles.
 - Abdominal muscles: a child lies on the back, legs are bent and feet are on the ground. A child takes a deep breath and while exhaling, blows the air towards his knees by moving the head up.
3. month exercises:
- A child lies on the back, knees are bent and feet are on the ground. There is a small object (for example a ball) placed between its knees. We tell a child to move his buttocks up and down. A child has to be careful, not to bend the lower back.
 - A child is kneeling; head is on the level of the back, looking down. We encourage a child to take a deep breath and while exhaling, we tell a child to say "shshshsh". Abdominal muscles are involved.
4. month exercises:
- Ankle movements. A child lies on the back, legs are bent in 90 degrees and child performs all different kinds of ankle movements.
 - Thigh muscles involvement. A child presses the feet ball between thighs.

This simple description provides a sample of exercises that are advised by professionals to perform when a child is having a flat foot. It can not be forgotten to stretch feet muscles every time before and after the exercise.

3.2 The measurement process

These entries were determined for the purpose of the measurement:

- the age of children
- the weight and the height
- the size of the foot
- flat foot and valgosity degree

- peak pressure measurement

These entries were recorded to the pre-made tables:

Table I : Table for the entries recording

Number	Age	Height (cm)	Weight (kg)	Size of the foot	Insole (type)

Note: The complete entries are listed in the appendix P I.

3.2.1 Height and weight measurements

Body height (cm) was measured with the measuring-tape attached to the wall. The proper value was recorded to the table.

Body weight was measured on the scale.

3.2.2 Foot size measurement

Foot size was measured on the equipment called podometer. A child stepped on the glass board marked with the foot sizes. The value was recorded to the table.

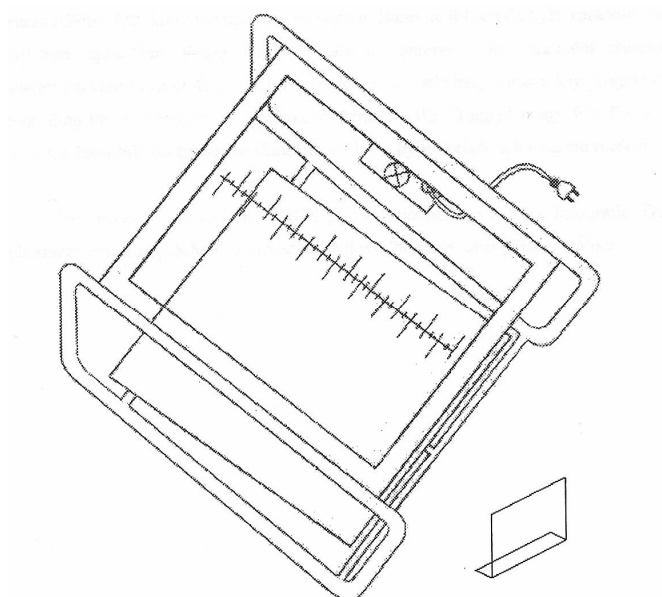


Figure 7. The scheme of the podometer

3.2.3 The flat foot and valgosity degree detection

The flat foot was detected on the podometer. A child stepped on the glass board of the podometer with both feet and the mirror-like surface showed the view of the footprint. The picture of the footprint was taken with a digital camera placed on a tripod.

The valgosity was measured on the podometer with the assistance of goniometer. A child stepped on the glass board and the goniometer was attached to his/hers right heel. The hand of the goniometer was set towards the inner part of the knee and the value was recorded. The same procedure was repeated with the left foot.

3.2.4 Peak pressure measurement

This measurement was performed on the PEDAR[®] equipment supplied by the Novel GmbH company in Munich. This equipment is used for measuring the pressure between the foot and the insole of the shoe. It consists of measuring insoles (different sizes), equipment used for transferring the data to computer and a software.

The measuring insole was chosen and placed in the child's shoes. All cables were connected to a computer. A child was told to walk 10 meters back and forth. The software recorded the walking pattern in the computer, while walking. The procedure was repeated three times.

3.3 Data processing

3.3.1 Creation of the masks

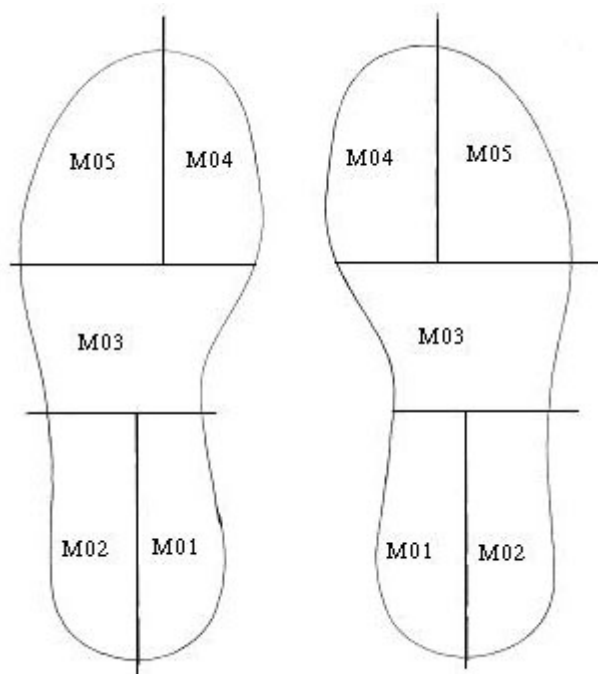


Figure 8. Separation of insoles of left and right foot to masks

There is a CREATION OF PERCENT MASK utility in the Novel-WIN 08.7 software. Insoles of the left and right foot were divided to 5 parts, called masks with this utility.

Table II: The description of masks

LEFT FOOT		RIGHT FOOT	
Mask	Description	Mask	Description
M01	Inner heel side	M01	Inner heel side
M02	Outer heel side	M02	Outer heel side
M03	Arch side	M03	Arch side
M04	Inner toe side	M04	Inner toe side
M05	Outer toe side	M05	Outer toe side

3.3.2 Evaluation of the average peak pressure in each mask

The MULTIMASK EVALUATION utility, found in the Novel-WIN 08.7 software, was used to evaluate the average peak pressure in each mask. The principle of this utility is to match a masks with steps, which were recorded to the computer while measuring the child's' pattern of walking.

3.3.3 Values of the average peak pressure for each mask for children with valgosity and flat foot, measured in 2004

There was a time of 3 months of activation of muscles after the first measurement. Children were exercising 2 times a week under the professional supervision, or they were exercising during the Physical Education classes at school. Then the second measurement was performed.

Children with valgosity and flat foot – LEFT foot

Table III shows that the overall load on the left insole has decreased. The peak pressure was detected on the inner side of the toe part of insole. There was a decreasing of pressure on the inner part of the heel detected and the decreasing of the pressure on the outer toe side and outer heel side of the insole.

Table III : Values of the average peak pressure in N/cm^2 in each mask of the left foot for children with valgosity and flat foot

	January 2004(N/cm^2)					April 2004(N/cm^2)				
	M01	M02	M03	M04	M05	M01	M02	M03	M04	M05
1	13,14	10,43	8,86	19,57	18	12,75	11,75	10	11,63	12,75
2	9,67	8,33	5,33	12,67	8,5	10	8,57	4,71	14,29	9,43
3	7,71	4,29	6,43	17,71	9,14	7,71	4,29	6,43	17,71	9,14
4	19	14,4	7,4	16,4	13,2	15,14	12,57	5,86	19,57	18,29
5	30,8	28	11	22	14,2	13,38	13	10,25	11,63	11,75
6	16,33	15,33	10,67	8	11,5	16,88	13,88	6,25	7,5	8,13
7	15,33	12,33	7,83	15,5	16,8	14,4	14	4,4	17,6	18,2
8	15,33	14,5	5,67	13,17	10	10,43	11,29	4	13,14	12,71
9	14,8	16,6	4,8	18	15	13,33	12,67	8	14	7,33
10	24	15,57	9,43	23,86	13,5	12,17	6,33	6,17	18	13,17
11	15,5	13,17	8,83	27,33	23,3	14	12,6	7,67	16,33	15,5
12	13,5	11	4,43	15,86	7,73	10,6	9,2	6,6	13,4	10,6
13	17,75	14,38	5,5	18,38	9,63	20,63	12,25	2,13	25	13,38
14	13	13	9,4	13,8	10,4	10,29	9,43	8,14	10,43	11,14
15	21	13,6	10,6	26,4	18,8	16,71	10,71	7,71	18,71	9,14
16	17,8	17,2	11,8	20,8	21	8,71	8,14	6,43	17,71	8,71
17	15,33	15,17	5,67	21	13	9,3	9,1	2,4	12,5	8,6
18	20,43	20,57	8,68	15,86	13,5	24,5	27,5	6	39	27
19	12,57	11,14	7,71	7	10,2	12	11,4	5	27,4	22,4
20	18	17,83	8,83	18,83	16,3	10,75	10,63	7,25	9,25	8,38
Ø	16,54	14,34	7,94	17,60	13,7	13,18	11,46	6,27	16,74	12,78
	M01	M02	M03	M04	M05	M01	M02	M03	M04	M05
	14,028					12,089				

Children with valgosity and flat foot – RIGHT foot

Table IV shows that the overall load on the right insole increased a little bit. The peak pressure was detected on the inner side of the toe part of insole.

Table IV: Values of the average peak pressure in N/cm² in each mask of the right foot for children with valgosity and flat foot

	January 2004(N/cm ²)					April 2004(N/cm ²)				
	M01	M02	M03	M04	M05	M01	M02	M03	M04	M05
1	17	17,37	10,87	20,87	15,6	11,1	13,9	8,2	9,2	12,4
2	5,5	5,17	2,67	7,67	4,33	8	6	5,83	16,83	12,83
3	8	6,29	8,14	15,29	15,1	8	6,29	8,14	15,29	15,14
4	9,4	9,6	8,8	7	13,8	14,38	13,25	9,75	14,75	15,88
5	21,67	20,67	10,17	17,33	13,8	20,33	16,33	18,83	13	20
6	7	17	11	11,33	10,1	25	26	11	24	15
7	9,4	9,2	5	5,8	6	18,6	14,2	4,8	13	14,4
8	14,63	13,88	6	13,5	8,75	15,29	15,71	10	12,43	15
9	16,2	14,4	5,4	18,8	9,6	18,8	18,8	8,8	11,8	9,4
10	23,86	15,71	10	28,6	15,7	20	12,43	6,43	17,57	11
11	23,14	18,43	8,43	29,57	23,1	13,2	11	5,4	25,4	15,8
12	7,06	5,38	5,78	9,19	9,69	12	12	5,6	17,2	8,8
13	10,14	8,71	1,57	6,86	5,14	22,86	19	2,72	19,57	10,86
14	8	10,6	4	11,2	5	10,38	10,25	9,13	9	11,75
15	18,25	15,5	11	12,25	11	10,14	7,29	5,86	17,29	9
16	24,6	24	9	17,6	13	7,5	10	9,5	3	7,5
17	7,67	10,17	4,67	10,33	10,3	10,67	10,67	4,44	7,22	6,67
18	20,5	20,17	8,33	26,33	13,5	30	30	9	25	16,5

19	10,13	12,5	4,25	4,75	5,25	11,57	11,29	6,43	16	15
20	17,83	13,33	7,83	12	7	10,44	13,67	10,44	8,78	8,89
ø	13,99	13,40	7,14	14,31	10,8	14,9	13,90	8,01	14,81	12,59
	M01	M02	M03	M04	M05	M01	M02	M03	M04	M05
	11,932					12,847				

Comparison of the left and right foot measured in 2004

The difference of the pressure in each mask is not outstanding, but it can be said that the left foot was more loaded in the first measurement. The second measurement proved that the load on the left foot decreased, and on the other way, the load on the right foot increased a little bit, making the loads more balanced than it had been before.

3.3.4 Values of the average peak pressure for each mask for children with valgosity and flat foot, measured in 2005

Children with valgosity and flat foot – LEFT foot

Table V shows that the overall load decreased a little bit and that is because of the inner and outer toe side decreased. This is the result of positive measurements based on the exercise trainings the previous year.

Table V: Values of the peak pressure in N/cm^2 for children with valgosity and flat foot, measured in January 2005 - Left foot

	January 2005 (N/cm^2).				
	M01	M02	M03	M04	M05
1	12,33	11,33	9,5	8,5	12,83
2	17,17	8,33	5,33	12	10,67
3	10,8	9,8	5,2	12,6	15,2
4	16,17	11,33	7,5	9,67	13,17
5	16,83	8,8	5,5	13,5	11,57
6	14,8	14	7	11,8	12

7	12	9	4	19,5	7,25
8	13	10,5	4,17	10,83	9,83
9	16,6	15,2	6,6	15,6	13,8
10	13,17	12	5,83	11,67	9,33
11	11,75	11,5	9,75	13	11,75
12	15,5	9	3,67	13	12,5
13	12,75	12,25	7,5	20,5	12,25
14	18,25	15,5	9,25	18,25	11,25
15	17,2	12,8	6,6	13	12,6
16	8	6	6,2	7,6	10,6
17	16,86	15	5,14	18	15,43
18	16,8	18	9,4	21,6	16
19	15	14,33	5,67	16	13,17
20	16,33	16	9	22,33	15,67
Ø	14,566	12,034	6,641	14,448	12,344
	MO1	MO2	MO3	MO4	MO5
	12,007				

Children with valgosity and flat foot – RIGHT foot

The overall load (as shown in Table VI) decreased based on positive results of the exercise.

Table VI: Values of the peak pressure in N/cm^2 for children with valgosity and flat foot, measured in January 2005 – Right foot

	January 2005 (N/cm^2).				
	MO1	MO2	MO3	MO4	MO5
1	15,5	17,17	9	12,5	13,17
2	13	9,6	5,4	16,6	9
3	12,83	12,67	7,33	8,33	14,17
4	16,6	13,8	7,8	11	13,8
5	14	9,97	6,5	17,6	9,4
6	16,8	16,3	7,3	13,8	13,8
7	10	8,5	5,3	18,5	7,75
8	12,75	11,5	5,5	10,25	9,25
9	15,4	14,4	6,8	4,4	7,6
10	14,75	13,75	4,75	14	8

11	12,2	9	4,6	9,8	7,2
12	13,4	12,6	3,8	15	9,6
13	14,2	14,8	8,2	10,8	12,2
14	13	12	7,33	26,67	10,33
15	22,75	18,7	9,25	14	14,25
16	9,17	9	4,17	8,33	6,83
17	20,15	13,86	6,71	13,43	16
18	24	27	11,5	32,5	18
19	13	12,8	16,8	18,4	19,4
20	20,5	20,25	9,5	21,5	13,75
σ	15,200	13,884	7,377	14,871	11,675
	MO1	MO2	MO3	MO4	MO5
	12,601				

Comparison of measurements, performed in 2004 and 2005

The overall decrease of load was based on the inner toe side decrease. It can be said that positive results of the 2004 measurements occurred in 2005 measurements.

Comparison of the values of the LEFT foot

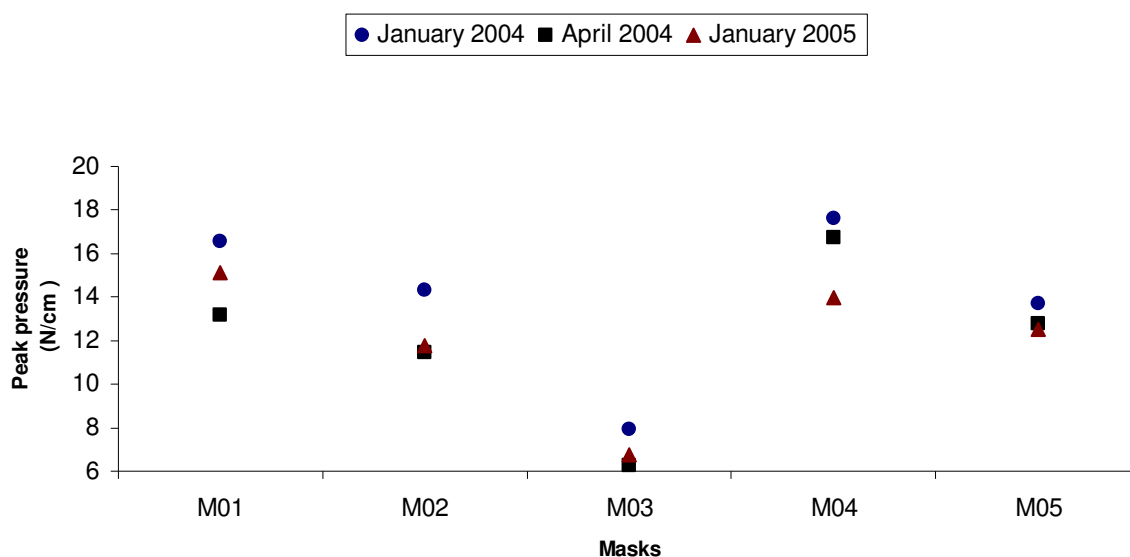


Figure 9. Comparison of the values of the left foot for all three measurements

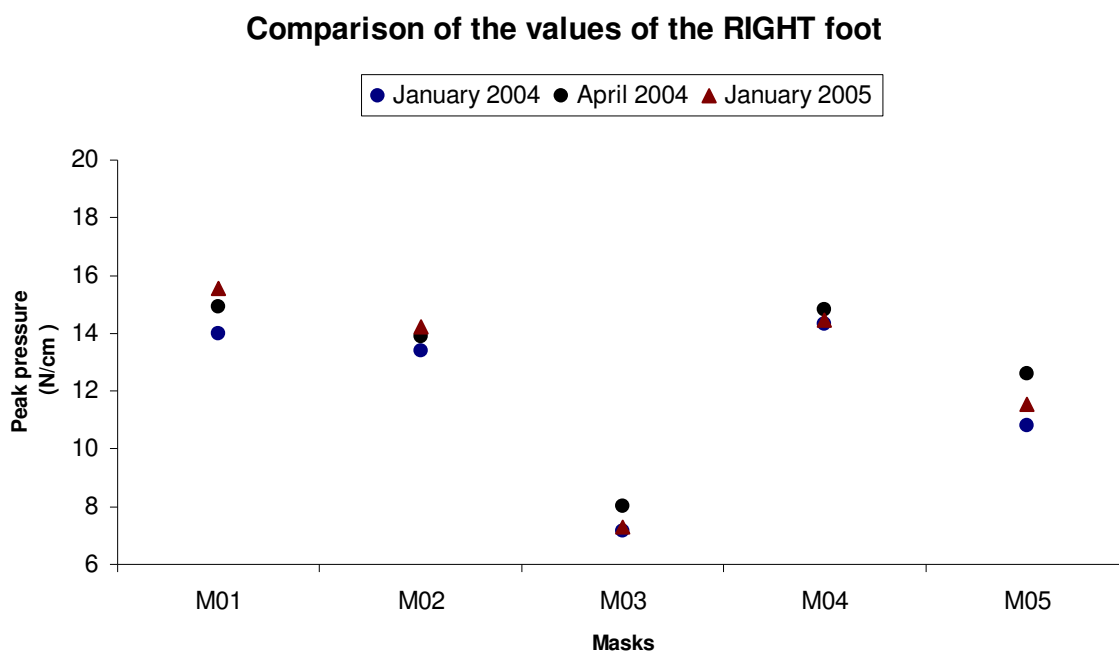


Figure 10. Comparison of the values of the right foot for all three measurements

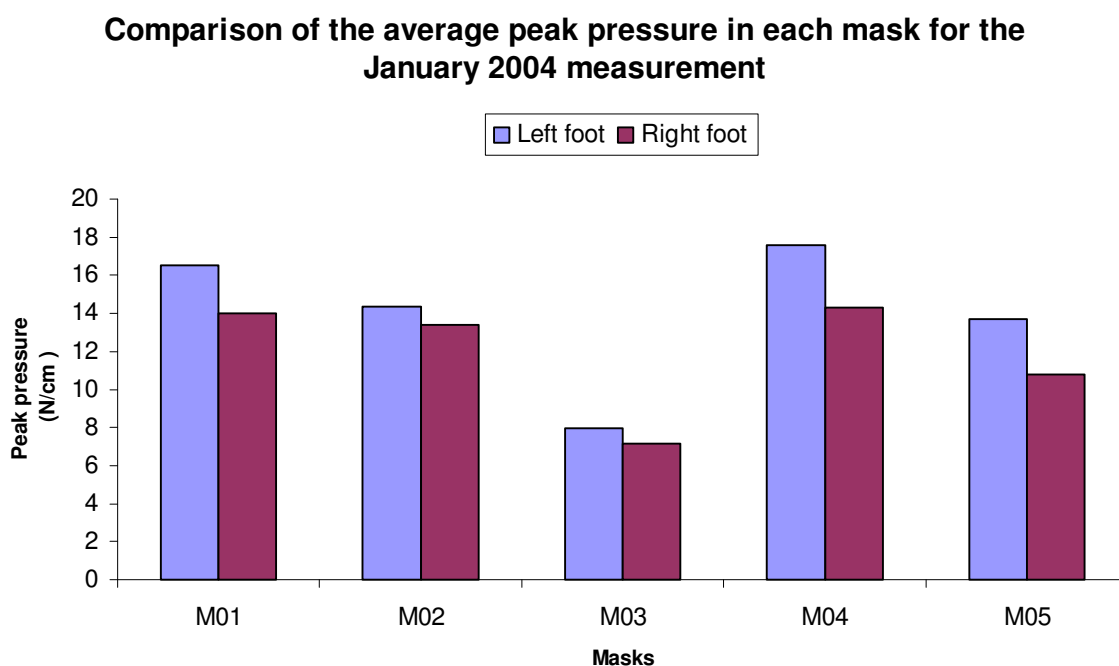


Figure 11. Comparison of the average peak pressure in each mask for the January 2004 measurement

Comparison of the average peak pressure in each mask for the April 2004 measurement

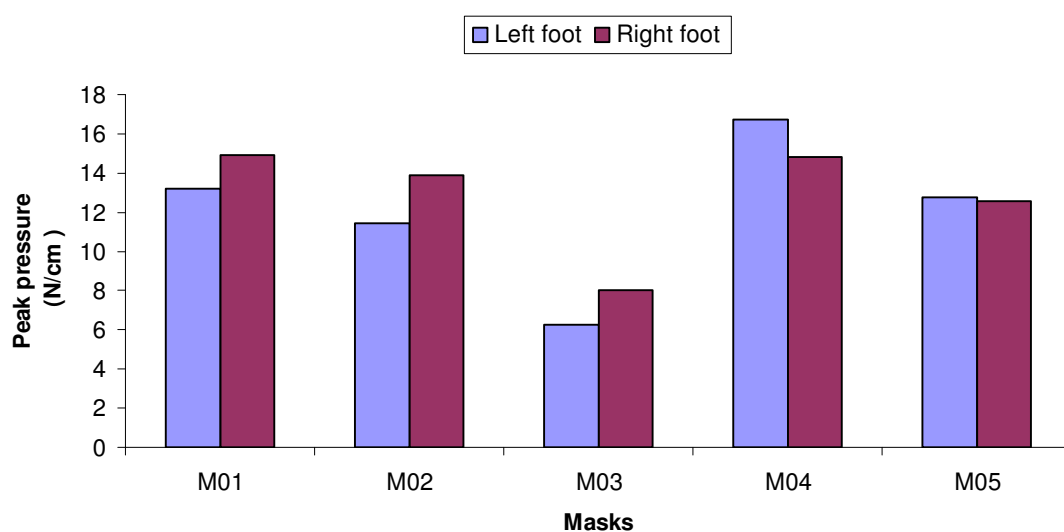


Figure 12. Comparison of the average peak pressure in each mask for the April 2004 measurement

Comparison of the average peak pressure in each mask for the January 2005 measurement

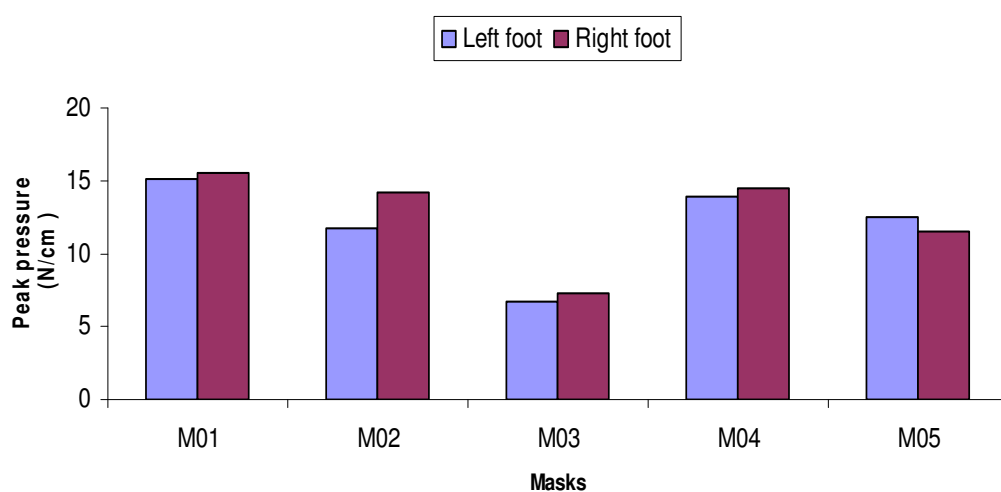


Figure 13. Comparison of the average peak pressure in each mask for the April 2004 measurement

The comparison of values for the right foot and the left foot shows the positive results in balancing both feet. As in 2004, the conclusion can be drawn that children

loaded the left foot more than the right foot, now it can be said that the load is equally balanced between the left and right foot.

3.3.5 Values of the average peak pressure for each mask for other children measured in 2004

Table VII shows us the values of peak pressure measured in 2004 with children that were not said to have the flat foot or valgosity. These children did not exercise. They were re-measured in 2005.

Table VII: Values of the peak pressure in N/cm^2 for other children, measured in 2004

	Left foot					Right foot				
	M01	M02	M03	M04	M05	M01	M02	M03	M04	M05
21	6,57	7,14	6,86	11	7	17,86	16,14	8,86	23,5	22
22	10,33	10,83	6,5	18,67	12,17	8,6	9,6	6,2	14	14,2
23	6,91	6,82	4,91	8,82	11,23	8,8	9,5	8,7	5	13,7
24	20,8	14,4	10,6	11	24,8	25,5	16,5	4,57	17,67	16,17
25	15,67	15,5	5,833	16,83	12,5	12,4	11,2	7	20,4	13,4
26	27,67	22,83	6,17	16,17	9,833	16,14	18,14	9,57	18,14	11
27	12	9,1	2,67	8,67	6,17	4,5	4,7	1,1	4,7	3,7
28	13,2	11	6,25	10,75	13,75	11,8	10,8	4	9,6	10,8
29	12,57	12,14	5,29	14,29	11,14	16,86	14,14	8,71	12,71	14,14
30	16,5	21,13	10,75	16,88	10,5	10,58	14	9,58	12,75	8,5
31	11,38	9,88	5,13	14,38	8,75	10,5	9,13	5	8	6,75
32	11,17	10,17	9,17	25,5	19,5	16,83	15	10,17	24,5	17
33	13,86	13,57	4,43	17,71	9,57	11,67	11,17	7,33	6,67	6

34	16	14,6	8,6	15,4	11	18,2	20	6,8	18,4	9
35	16,33	15,78	5,67	15	8,33	16,88	17,13	5,38	19	10,5
36	15,57	15,29	8,43	16,43	14,86	17,75	15	6,13	19,88	13,38
37	16,83	17,5	19,33	19,33	25,5	18,5	18,33	9,83	25,83	16,67
38	14,8	16,6	4,8	18	15	16,2	14,4	5,4	18,8	9,6
39	17	11	6,83	20,33	9,5	14,17	13,33	6,83	17,33	9,67
40	13,75	13,5	9	18,5	7,25	18	17,5	12,17	10,67	10,5
41	18,25	14,13	7,25	14	16,38	16,63	13	6,75	9,25	12,38
42	5	2,63	5,75	10,63	10	10,38	8,75	9	6,63	10,88
43	18,75	15,38	5,75	18	12	12,38	11,25	6,5	13	13,75
44	13,43	14,43	5,71	13,71	9,71	14,29	17,86	7,43	14,71	8,71
45	15,5	12,88	6,88	17,38	7,63	14,14	12,23	7	15	4,71
46	16,25	13,38	5,38	9,38	9,25	22	18,86	11	6,29	12,14
47	18,14	16,86	9,57	23,57	17,29	24,86	20,86	11,86	20,71	16,29
48	14,25	12,88	8,13	12,5	14,75	11,17	13,17	12,33	15,67	17
49	17,5	16,83	8,33	10,5	9,5	10,75	8,75	7,25	14,25	14
50	20	18,6	11	15,5	12,5	19,17	19,83	7,33	18,33	10,83
51	12,4	12	6,71	17,43	6,86	14,57	12,71	4,14	9,43	7,71
52	11,88	12	4,75	11	10,63	12,13	10,75	6,5	8,13	9,5
53	16,6	13,8	8,4	14,2	13,2	10,25	10,75	8,25	6,75	10,25
54	14,5	13	7	15,67	16,83	19	19	10	19	20

55	8,13	7,63	2,75	14	10,25	8,86	8,43	5,14	10,71	11,43
56	25,2	22,6	7,4	19,6	16,4	19,2	19,6	8,6	15,2	15,8
57	13,3	12,6	8	14	7,33	18,8	18,8	8,8	11,8	9,4
58	11,57	11,29	7,71	10,14	11	17,14	12,29	7,86	6,43	8,71
59	11,5	10,2	3,5	14,88	9,25	13,5	11,5	5,5	6,75	15,38
60	15,33	13,83	7,17	18,17	12,67	17,14	13,85	5,29	21,86	14,43
61	10	10	4,8	9,25	11,63	11,33	12,33	8,33	9,22	16,22
62	10	9,17	4,83	13,67	11	9	7,86	7,29	5,57	9,29
63	16,17	14,33	5,33	14,33	11,67	17,67	17,67	4,33	12	12,5
64	20	11,4	7,6	17,6	11,8	25	23,25	4	16,75	12
65	8,86	8,71	6,71	13,71	13,71	10,5	9,5	7,33	13	11,5
66	11	16,8	9,8	10,2	25	13,2	16	10,2	10,8	19,2
67	11,67	10,5	6,5	21	12,5	11,67	12,17	6,67	19,67	8,5
Ø	14,3	13,12	7,02	15,05	12,3	14,81	13,97	7,40	13,7	12,11
	M01	M02	M03	M04	M05	M01	M02	M03	M04	M05
	12,37					12,40				

3.3.6 Values of the average peak pressure for each mask for other children measured in 2005

Table VIII shows the values of the peak pressure for other children measured in 2005.

Table VIII: Values of the peak pressure in N/cm^2 for other children, measured in 2005

	Left foot					Right foot				
	M01	M02	M03	M04	M05	M01	M02	M03	M04	M05
21	15,75	15	18	25,5	26,75	17	16,4	12,2	24,6	20,8
22	21,25	14,5	7,25	18,5	10,75	20,25	15,75	9,5	6,75	9,5
23	20	13,6	13,2	12,2	19,2	12,4	15,6	14	15,6	19,2
24	21,6	20	8,83	13,5	27,33	29,17	23	6,67	17	18,67
25	14,67	13,83	5,83	13,67	12,17	13	12,83	6	12,67	10
26	22	19	8	16,25	15,75	27,2	26,8	7,2	21,6	16
27	13,5	10,5	7,25	18,5	11,25	14,75	13	5,5	24,8	15,8
28	12,5	10	4,83	13,17	17,5	12,8	12,8	5,2	14,4	19,8
29	18,8	17,8	9	14,8	17	16,4	15	5,6	21,8	18,6
30	17,8	16,4	17,8	14,4	19,8	19,2	19,8	10,8	11,8	13,8
31	16,2	14,2	7,4	16,4	13,2	15,17	12,83	6,67	28,83	16,1
32	15,5	12,83	11,5	13,67	14	13,67	12,5	4,67	15,83	7,33
33	12,2	11,4	10,6	10	12,6	12	12,17	9,5	7,83	10,17
34	9,67	9,83	10,5	5,17	10,5	12,17	13,5	8,17	9,5	9,33
35	13,5	12,5	6,83	10	5,83	12,67	12,17	6,17	10,5	6,67
36	23,8	18	4,2	11,4	10,8	18,4	17,4	6,6	8,4	9,8
37	14,83	24,5	11,83	14,5	13	20,6	17	8,4	17,8	8,2
38	14	14	10	14,67	11,67	15,5	15,5	8,5	13,5	11
39	16,67	14,5	6,33	11,83	10,17	21,2	17,2	5,6	11	8,8
40	21,67	22,33	12,5	10,5	18,67	29,17	25,33	11,5	12,67	17,83
41	10,17	9,67	6,17	10,67	11,33	10	8,8	7,6	11,4	10,4

42	15	6,67	2,83	11,83	8,83	16,14	11,86	6,29	9,86	11,57
43	9,8	9,8	7,8	9	10,4	7	7,8	7	8,2	8,6
44	13,67	7,83	4	13	6,33	6,1	5,18	2,82	6,9	3
45	13	10,2	7,6	9,6	9	10,5	10,33	7,67	10,33	9,67
46	18,83	17,83	9,83	16,17	16,67	16,4	16,4	11,4	13,6	16,4
47	9,25	9,25	5	8,25	7	10,6	10,8	6,2	7	7,8
48	15,4	13,2	5,8	7	7,2	14,75	14,5	5,75	7,75	7,5
49	11,14	11,14	9,29	8	11,2	16,4	13,2	4	15	6,8
50	9,4	6,6	9	5,6	9,8	10	8,4	6,2	7,4	7,4
51	13,2	11,8	4,6	10,8	8,2	12,4	12,4	5,4	11,2	10,2
52	13,43	12,29	8,14	12,14	12,43	11,86	11,86	6,29	11,86	10,43
53	12	10,75	7,75	7	9	12,6	12,2	8,2	9,6	7,2
54	9,4	8,2	6,4	10,4	13,2	8,6	8,2	5,8	13	13
55	12,88	13,38	5,38	11	10,5	9,43	8,43	5,57	12,86	11
56	10,5	10	5,75	11,75	10,75	8,25	7,5	5,25	12,5	10
57	14,8	14,2	10,4	14,2	13,4	14,25	12,5	6,75	14,75	13,25
58	14,8	10,8	7,6	7,2	12	17	16	3,5	14,25	9,25
59	16	16	8,2	16	14,2	17,5	17,5	6,75	15	9
60	13,83	11,33	5	10,3	7	10,6	9,4	7,2	8,8	8
61	12,2	11	4,2	8,4	9,6	10,4	10,4	3,8	7	6,2
62	14,4	13,2	10,6	11,8	12,2	14	12	6,6	15	15
63	20	20,8	5,4	14,2	13,2	16,25	15,25	4	17,75	13
64	17	12,25	4,25	14,75	13,5	15,25	14,5	4,5	17,5	12,5
65	13,83	13,83	9,5	13	13	14	14	6,17	16,33	14,33
66	10,2	9,5	6	16	14	12,25	12,25	5,75	13	10

67	11,6	9,2	4,2	11,4	8,4	10,4	9,6	6	5,8	12,2
ø	14,7	13,09	7,92	12,29	12,55	14,58	13,57	6,82	13,20	11,51
	M01	M02	M03	M04	M05	M01	M02	M03	M04	M05
	12,11					11,94				

Comparison of measurements, performed in 2004 and 2005

It can be viewed that the decrease of the load was not that visible as with children that were exercising. There was a slight decrease, but this was based not only in natural development of children feet, but the whole body as well.

Comparison of the values of measurements made in 2004 and 2005 - the left foot

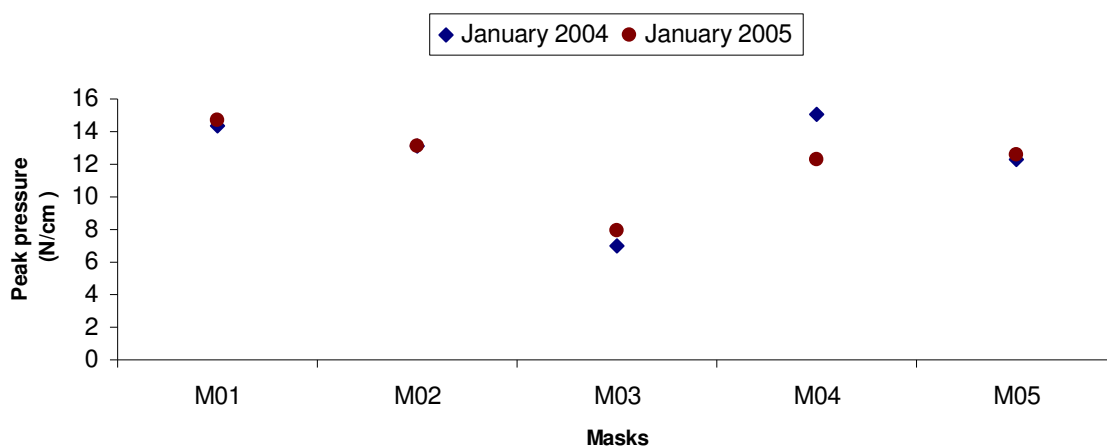


Figure 14. Comparison of the values of measurements of the left foot

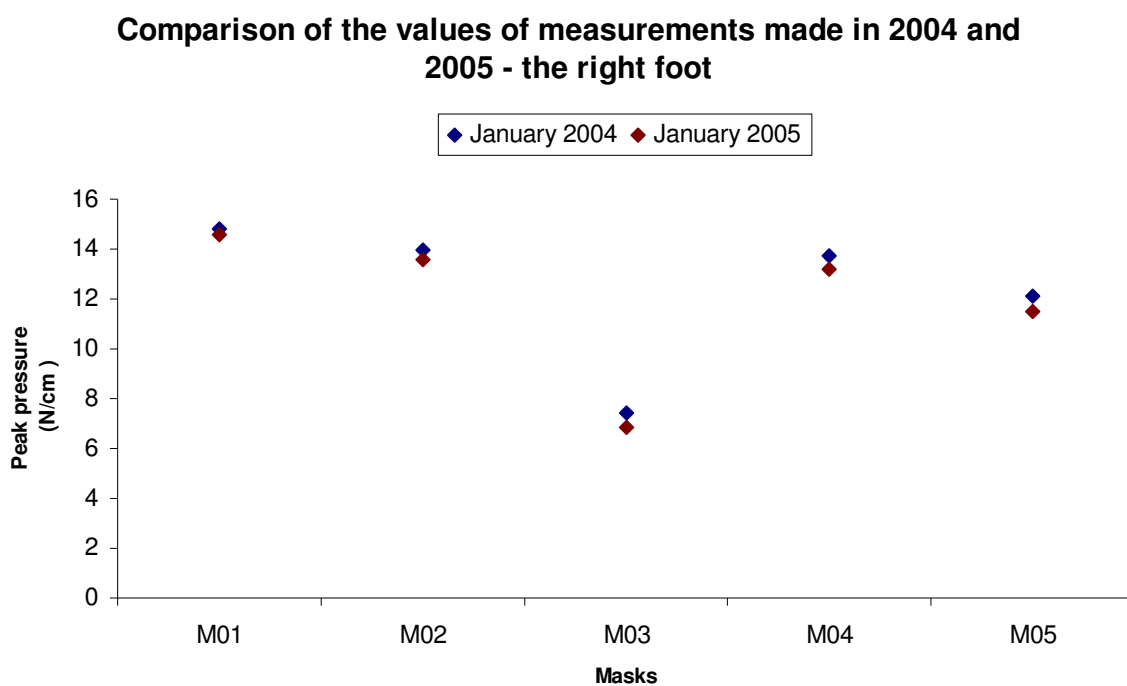


Figure 15. Comparison of the values of measurements of the right foot

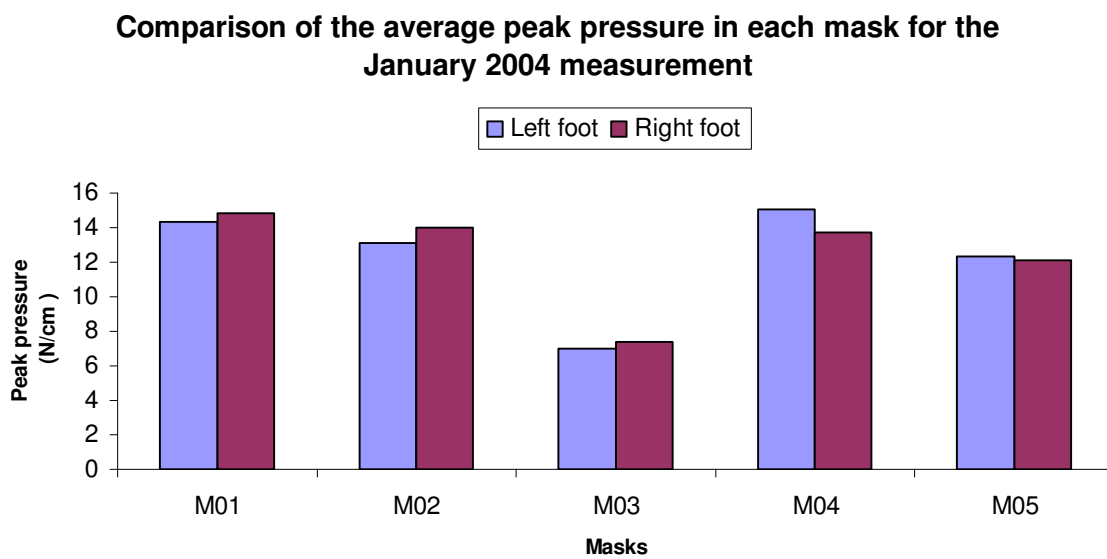


Figure 16. Comparison of the average peak pressure in each mask for the January 2004 measurement

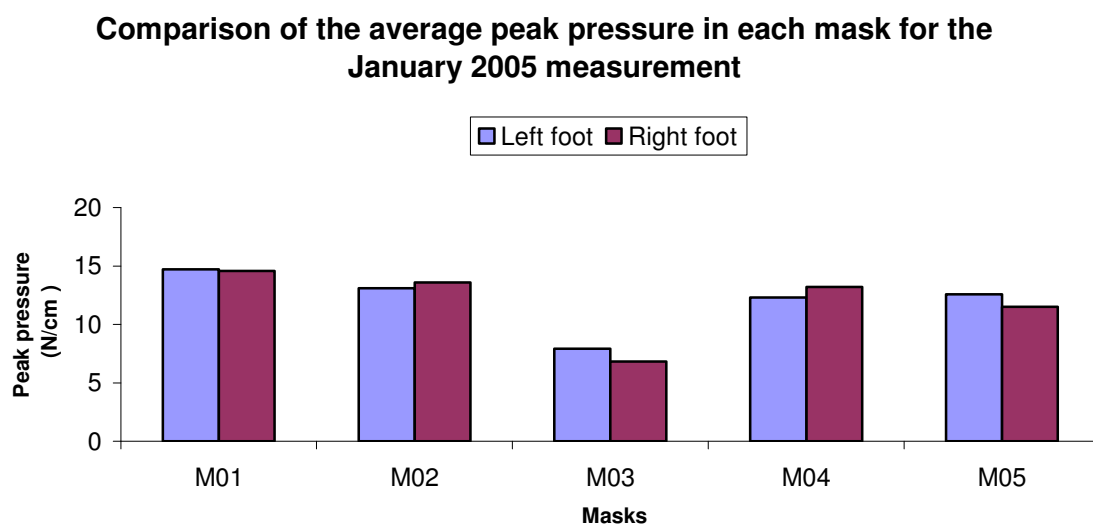


Figure 17. Comparison of the average peak pressure in each mask for the January 2005 measurement

The difference between children with valgosity and flat foot and other children is not based on the different peak pressure values, but on unbalanced feet load. As it can be seen in Figures 15 and 16, children without the valgosity and flat foot have their loads balanced better on both feet than children with the valgosity.

3.3.7 Values of the average peak pressure for each mask for the second group of children, measured in December 2004 and March 2005

Second group of children measured in December 2004 and re-measured in March 2005, exercised mostly at home under their parent's supervision. Many children admitted that they were not exercising properly and regularly.

Table IX: Values of the peak pressure in N/cm^2 for the second group of children measured in December 2004

	Left foot					Right foot				
	M01	M02	M03	M04	M05	M01	M02	M03	M04	M05
68	17,38	17,25	6,88	13,5	12,63	25,11	14,88	9,11	11,56	12,89
69	13	11	7	20	17	8,38	7	5,13	7,75	9,63
70	14	9,9	8,1	15,9	10,82	13,67	11,33	5,58	9,92	8,58
71	9,8	10,2	11	16	11,6	8,78	9,88	10,56	12,11	9,67
72	15,89	13,89	6,44	15,44	9,22	15	13,11	4,78	9,78	7,33
73	17,15	13,3	5,85	13,69	12,1	15,71	11,71	5,5	12,6	10
74	14,42	13,92	8,33	17,83	12,92	14	14	7,77	18,92	11,01
ø	14,52	12,78	7,65	16,05	12,32	14,37	11,70	6,91	11,80	9,87
	M01	M02	M03	M04	M05	M01	M02	M03	M04	M05
	12,66					10,93				

Table X : Values of the peak pressure in N/cm^2 for the second group of children measured in March 2005

	Left foot					Right foot				
	M01	M02	M03	M04	M05	M01	M02	M03	M04	M05
68	18,13	16,87	6,13	15,5	13	30,78	22,44	11,44	12,11	14,22
69	14,9	11,4	7,3	16,2	14,6	15,5	13,2	6,1	10,3	8,3

70	10,67	9,78	10,89	20,33	15,11	12,2	11,1	8,9	20,9	19,5
71	13,14	10,6	8	16,14	7,14	11	9,83	7	11,12	6,7
72	11,27	10,55	6,36	10,36	10,91	10	8,83	5,75	13,08	12,92
73	12,55	12	6,9	10,46	9,09	12	11,36	6,46	10,64	9,55
74	11,43	14,43	6,57	12,86	10,57	10,92	10,92	7,83	11,75	11,5
Ø	13,15	12,23	7,45	14,55	11,48	14,62	12,52	7,64	12,84	11,81
	M01	M02	M03	M04	M05	M01	M02	M03	M04	M05
	11,77					11,89				

Comparison of measurements for the second group

The comparison of two measurements shows us the decrease of overall values for the left foot and the increase for the right foot. The increase on the right foot is so evident that there was an increase in every mask, but the overall values show that the load was more balanced.

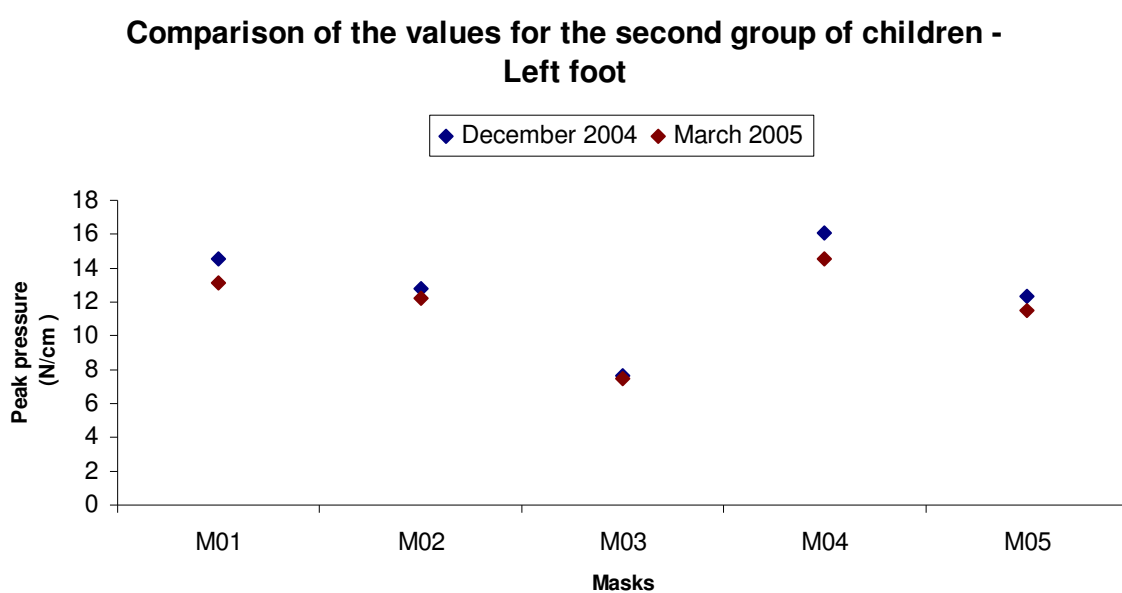


Figure 18. Comparison of the values for the second group of children, their left foot

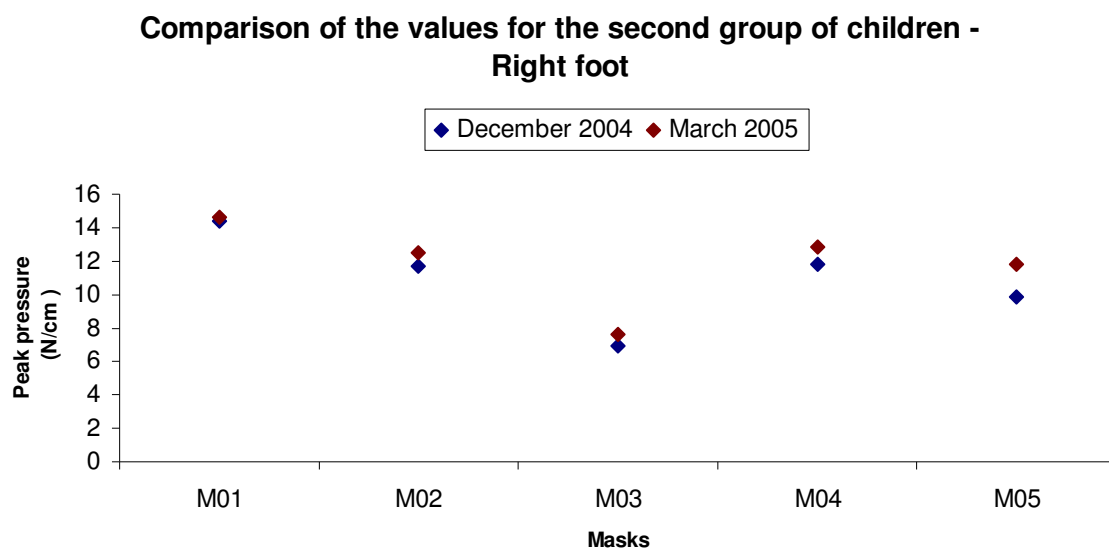


Figure 19. Comparison of the values for the second group of children, their right foot

CONCLUSION

Since the flat foot and valgosity belong to two of the most occurring foot illnesses among children between the ages 5 to 12, the main aim of this Master thesis was to prove the positive impact of the exercise and training of the foot muscles in the prevention of mentioned illnesses.

This impact was researched by means of monitoring the changes in plantar pressure distribution of both right and left foot. There were 74 children measured. The measurements took place Slovenská Elementary in Zlín and at Hvozdná Elementary school. 20 children were found to have valgosity and flat foot at Slovenská Elementary. The results of the previous study in 2004 were also taken into consideration.

Both groups of children were measured by PEDAR[®] system and there pressure distribution patterns were recorded. We aimed to find out if the load of the inner side of feet in children with monitored illnesses was under the influence of exercising going to decrease. These children were taught exercises which they performed twice a week under the professional supervision. After three months of activating their muscles by the exercise, the re-measurement was performed.

Results show that the main difference between children with valgosity and the other group is in the overall balance of their feet. As figures show children with valgosity and flat foot had more load on their left foot and after free months of activating their muscles, the load was balanced on the average. The re-measurement made in 2005 proved positive changes by means of balancing the left and right foot. In this particular case, the exercise may not have been the only means of improvement. As the natural development of the child's body needs to be taken into consideration as well.

From these positive results a conclusion can be made that the exercise of the foot muscles has positive impact on the prevention and the correction of the foot illnesses in pre-pubertal age. Therefore the exercising should not be underestimated by professionals who treat feet illnesses. Attention should be paid to the posture of the whole body as well. Bad posture and illnesses such as scoliosis have an influence on the pressure distribution. More balanced foot pressure distribution influences positively the whole body posture of a child and contributes to his/her well being.

BIBLIOGRAPHY

- (1) ROSSI, A. William, TENNANT, R. *Professional Shoe Fitting*. New York: NSRA, 1984.
- (2) KUBÁT, R. *Péče o nohy*. 1.vyd. Praha: AVICENUM, 1985.
- (3) ŘÍHOVSKÝ, R. *Anatomie a fyziologie*. Praha 1975.
- (4) LINDSAY, David T. *Functional human anatomy*. 2.edition. St.Luis: Mosby, 1996. ISBN: 0-8016-6471-3.
- (5) JONES, F.Wood. *Structure and function as seen in the foot*. London: Bailliere, Tindall and Cox, 1944.
- (6) RYCHLÍKOVÁ, E. *Funkční poruchy kloubů končetin*. 1.vyd. Praha: AVICENUM, 1980.
- (7) HAUSER, Emil D. W. *Diseases of the foot*. 2.edition. Philadelphia: W.B.Saunders Company, 1950.
- (8) *Hallux valgus and preferred shoe types* [online]. [cit. 3/15/2005]. <http://www.kfshrc.edu.sa>.
- (9) DUNGL, P. *Ortopedie a traumatologie nohy*. 1.vyd. Praha: AVICENUM, 1989.
- (10) *Foot physicians* [online]. [cit. 3/20/2005]. <http://www.footphysicians.com>.
- (11) SOSNA, A., VAVŘÍK, P., KRBEC, M., POKORNÝ, D., a kolektiv. *Základy ortopedie*. 1.vyd. Praha: TRITON s.r.o, 2001. ISBN: 80-7254-202-8.
- (12) JANÍČEK, P., a kolektiv. *Ortopedie*. 1.vyd. Brno: Masarykova Univerzita, 2001. ISBN: 80-210-2535-2.
- (13) KUBÁT, R. *Cvičení pro děti při plochých nohách*. 10.vyd. Praha: Ústav zdravotní výchovy, 1984.
- (14) BOTLÍKOVÁ, V. *Vyrovňovací cvičení kyčle, kolena, ploché nohy*. Praha: Svojtka a Vašut, 1992.
- (15) *The stretching handbook* [online]. [cit. 5/18/2005]. <http://www.thestretchinghandbook.com/archives/warm-up.htm>.

LIST OF SYMBOLS AND ABBREVIATIONS

MO1 - Mask for the inner heel side

M02 - Mask for the outer heel side

M03 - Mask for the arch side

M04 - Mask for the inner toe side

M05 - Mask for the outer toe side

m - the weight (kg)

$\bar{p}$ – the average of the peak pressure (N/cm²)

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APPENDIX

P 1 : Table IA - ID : Table for the entries recording

P 2 : Flat foot

Table I.: Table for the entries recording

Number	Age	Height (cm)	Weight (kg)	Size of the foot	Insole (type)
1	9	142	31,5	21	T
3	9	136,5	28	21	T
4	10	145	39	22	T
5	10	154	33	22,5	U
6	9	146	37	21,5	T
7	10	152	32	22	S
8	9	146	45	21	T
9	9	148	33	21	T
10	9	150	52	23	V
11	9	143	36	22,5	U
12	9	138	29	18,5	T
13	10	131	26	21	T
14	10	137	28	19	S
15	10	143	33	21	U
16	10	150,5	46	22	U
17	10	141,5	27,5	20,5	S
18	10	149	53	22,5	U
19	10	138	34	22	T
20	10	153	39	23,5	W
21	10	148	35	21,5	S
22	10	146	37	23	W

23	9	137	32	21	S
24	9	139,5	30	21	S
25	10	150	36	22,5	T
26	10	141	27	20,5	S
27	9	131	22	20	R
28	10	134	24	19,5	R
29	9	133	27	19,5	S
30	10	140	38	21	S
31	9	128	27	20	R
32	10	140	31	22	T
33	10	137	27,5	20	S
34	10	138	34	20	T
35	9	137	31	21,5	T
36	10	146	30	22	T
37	10	142	39	23	U
38	9	140	26	21,5	T
39	10	147	36,5	22	T
40	10	135	27	21	S
41	9	136	26	20,5	T
42	9	130	24	18	Q
43	10	142	39	22,5	T
44	9	136	39	22	T
45	9	127	20	21	T

46	9	138	31	21	T
47	9	153	57	23,5	U
48	10	148	31	22	T
49	9	131	25	20	T
50	10	144	32	21,5	T
51	10	139	31	20,5	T
52	9	152	39	23,5	V
53	10	139	29	21	T
54	9	142	33	18	T
55	9	139	29	18	R
56	9	145	30	22	T
57	9	127	22	18,5	Q
58	9	150	36	22	T
59	9	135	24	19,5	S
60	9	140	29	22	T
61	9	134	25	22,5	T
62	9	126	23,5	22	R
63	10	150	34	23,5	U
64	10	150	36	23,5	T
65	9	136	27	21	S
66	10	147	36	23	U
67	10	149	31	22,5	T
68	12	137	31	19	S

69	6	115	20	15	Q
70	7	115	19	15,5	Q
71	7	109	16	14	Q
72	10	144	38,5	24	T
73	5	113	19	14,5	Q
74	5	116	20	14,5	P

P 2.: Flat foot

