

## Analysis of foot load during ballet dancers' gait

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Ballet is an art that puts extreme demands on the dancer's musculoskeletal system and therefore significantly affects motor behavior of the dancers. The aim of our research was to compare plantar pressure distribution during stance phase of gait between a group of professional ballet dancers and non-dancers. Thirteen professional dancers (5 men, 8 women; mean age of  $24.1 \pm 3.8$  years) and 13 non-dancers (5 men, 8 women; mean age of  $26.1 \pm 5.3$  years) participated in this study. Foot pressure analysis during gait was collected using a 2 m pressure plate. The participants were instructed to walk across the platform at a self-selected pace barefoot. Three gait cycles were necessary for the data analysis.

The results revealed higher ( $p < 0.05$ ) pressure peaks in medial edge of forefoot during gait for dancers in comparison with non-dancers. Furthermore, differences in total foot loading and foot loading duration of rearfoot was higher ( $p < 0.05$ ) in dancers as well. We can attribute these differences to long-term and intensive dancing exercises that can change the dancer's gait stereotype.

*Key words: walking, biomechanics, gait analysis, plantar pressure, forefoot, rearfoot*

### 1. Introduction

Human foot is a fundamental segment of upright standing and locomotion [1]. So the foot must be able to support body mass by ensuring sufficient postural balance, absorb shock, adapt to ground surfaces and transmit forces efficiently during gait and other bipedal activities [1], [2]. All of these functions can be fulfilled by its anatomic structure [3] and using complex movements performed in individual arch.

During dancing, excessive ranges of motion are required, especially during ballet, where extreme ankle position is executed. In *en pointe* position, where the foot is excessively plantar flexed, the tips of the great toes must bear a lot of weight [4]. This position allows higher mobility of the ankle, but causes ankle instability, which makes it one of the most vulnerable joint to injury during dancing [5]. In order to prevent any degenerative and traumatic injuries such as, e.g.,

ankle sprain, it is important to involve muscle activation and ligament in this position. [6].

Although the system of classical ballet training is based on the anatomical possibilities of the human body [7], dancers are often forced to work in a range of movements, without reference to the nature of the anatomical joint [8], [9]. Hence the lack of movement in the joints they often use compensatory strategies (e.g., foot pronation) [10]. Overloaded structures of the foot can deteriorate possibilities of shock absorption during heel strike of gait. These forces must be absorbed in higher body segments, which are not adapted for this task and then it results in their damage. Ankle dysfunction also affects function of the foot [11].

Recent research [12]–[14] has proved that the injuries of the ankle and the foot happen most frequently during dancing. The incidence of chronic injuries, from overloading, is more frequent than the acute injuries. Also ballet shoes (called “pointe shoes”), which

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are used especially by women, can cause foot deformities when they are used for a longer period of time [15].

While the majority of published scientific papers are devoted to injuries and deformities, which could be associated to the group of ballet dancers, research into their causes is missing. Furthermore, there is little information of how extreme ballet poses, which affect the physical structures of the dancer, change their daily movement patterns. Therefore, it is necessary to devote further research to better understanding of the causes of dancer's injuries and recommended treatment and preventive strategies over a long period.

The observation of the relationship between the long-term, intensive dancing exercises and analysis of plantar pressures distribution during gait could be beneficial for solving this issue. Moreover, the quantitative analysis of gait is a real scientific challenge [16]. The aim of the present study was to compare pressure peaks, total loading and duration of the loading in selected foot areas between groups of professional ballet dancers and non-dancers.

## 2. Materials and methods

### 2.1. Subjects

The experimental group involved 13 professional dancers (5 men, 8 women; mean age of  $24.1 \pm 3.8$  years; mean height of  $170.2 \pm 8.5$  cm; mean weight of  $58.3 \pm 11.2$  kg) from the ballet company of Moravian theatre in Olomouc. The elite level in ballet dance and no operations of lower extremities were established as the inclusion criteria. The intensity with which the subjects performed the dancing practice was from five to six times a week with the duration from 3 to 8 hours per day. The subjects have performed the dancing experience for  $16.1 \pm 4.8$  years. Nine of the subjects suffered with subjective problems of musculoskeletal system.

The control group involved 13 non-dancers (5 men, 8 women; mean age of  $26.1 \pm 5.3$  years; mean height of  $173.3 \pm 7.3$  cm; mean weight of  $74.1 \pm 12.5$  kg). To be involved into the research, the inclusion criteria for members of this group were maximum competitive level in sport activities and also no operations of lower extremities. They performed sports activities such as football, basketball, running, fitness exercise, etc., with frequency 4 to 5 times a week.

### 2.2. Methods

Foot pressure data during gait were collected using a 2 m pressure plate (RSscan International, Olen, Belgium). The research participants were instructed to walk across the platform at regular pace (average velocity: ballet dancers  $1.28 \pm 0.12$  m.s<sup>-1</sup>, controls  $1.30 \pm 0.09$  m.s<sup>-1</sup>) barefoot. Three gait cycles were used for the data analyses.

### 2.3. Data processing

The gathered data were analyzed by the Footscan gait software (version 7.97). The foot was automatically divided into 10 areas: medial and lateral heel, midfoot, 1.–5. metatarsals (separately), big toe and toes (2.–5. together). If necessary, the manual correction of the division was applied. From each of the observed parts of foot, the following parameters were evaluated: % pressure peak (pressure peak of the area divided by the pressure peak of the sum of pressure of all areas), % contact (duration of the loading in a specific area divided by the duration of the whole foot loading), % pressure impulse (pressure impulse of the area divided by the pressure impulse of the whole foot). Before statistical processing the obtained values of both feet from three trials were averaged for each subjects. For statistical comparison (Statistica, version 9.0, Stat-Soft, Inc., Tulsa, USA) between the professional ballet dancers and non-dancers, the Mann–Whitney U test was applied. The statistical significance level was set at 5%. To determine the statistical significance we used Cohen's *d*. The effect size of our data was small ( $0.2 < d < 0.5$ ).

## 3. Results

The results showed significantly higher values ( $p < 0.05$ ) of the pressure peak in the big toe, the 1st and 2nd metatarsus area in the group of ballet dancers in comparison with the subjects from the control group. On the other hand, in area of the toes 2–5, the 5th metatarsus and the midfoot the pressure peak reached significantly higher values ( $p < 0.05$ ) in the control group. There is a tendency to higher values in the area of the medial heel in the group of dancers. On the contrary in the area of the lateral heel were higher values in the non-dancers group. However, no significant differences were found between heel areas (Fig. 1).

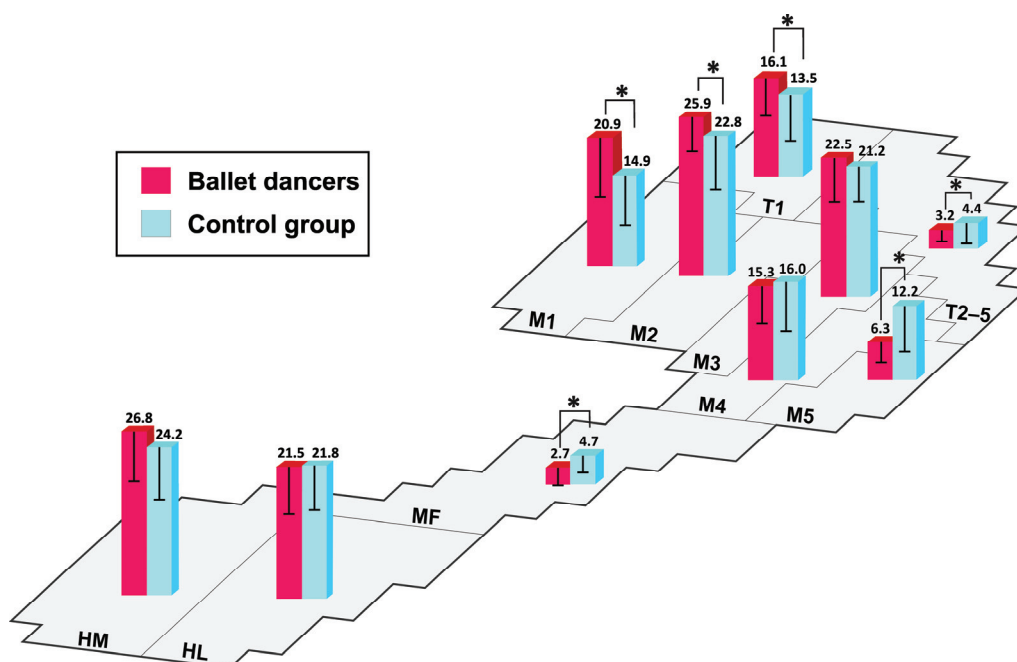


Fig. 1. Comparison of the ballet dancers and control group – % pressure peak: T1 – big toe, T2–5 – toes 2–5, M – metatarsus, MF – midfoot, HL – heel lateral, HM – heel medial, \* –  $p < 0.05$

Significantly longer duration ( $p < 0.05$ ) of the foot contact with the ground was found in both heel areas in the group of ballet dancers, whereas in the control group a significantly ( $p < 0.05$ ) longer duration was found in the area of the big toe, toes 2–5, midfoot and the 4th and 5th metatarsus (Table 1).

Table 1. Statistical analysis of the loading duration (% contact)

	Ballet dancers		Control group		$p$ values
	Mean	SD	Mean	SD	
Big toe	47.8	8.69	51.5	16.25	0.039*
Toe 2–5	30.2	8.98	40.8	21.50	0.004*
M1	63.5	11.38	64.4	16.95	0.323
M2	74.8	7.55	74.5	9.87	0.785
M3	77.2	5.41	79.0	4.92	0.055
M4	75.8	4.89	78.5	4.90	0.001*
M5	67.5	13.19	72.4	6.70	0.005*
Midfoot	45.3	19.63	50.0	8.60	0.003*
Heel medial	57.1	5.95	52.5	8.54	0.001*
Heel lateral	54.4	5.79	50.6	7.86	0.002*

SD – standard deviation, M – metatarsus, \* –  $p < 0.05$ .

The values of the pressure impulse in big toe and the 1st metatarsus area and both heel areas were significantly higher ( $p < 0.05$ ) in the group of ballet dancers. In comparison, in the area of the 4th and the 5th metatarsus and midfoot significantly higher values ( $p < 0.05$ ) were found in the control group (Table 2).

Table 2. Statistical analysis of pressure impulse (% pressure impulse)

	Ballet dancers		Control group		$p$ values
	Mean	SD	Mean	SD	
Big toe	6.9	3.25	5.8	4.46	0.005*
Toe 2–5	1.1	1.01	1.4	1.31	0.095
M1	10.8	5.19	7.8	4.95	0.001*
M2	15.4	4.50	14.3	6.88	0.092
M3	15.3	5.47	14.3	4.95	0.313
M4	10.8	5.25	13.3	6.78	0.026*
M5	4.5	2.90	9.7	8.35	0.000*
Midfoot	1.3	1.67	2.4	1.52	0.000*
Heel medial	17.1	5.96	13.3	5.98	0.000*
Heel lateral	12.6	3.76	11.4	4.38	0.019*

SD – standard deviation, M – metatarsus, \* –  $p < 0.05$ .

## 4. Discussion

To achieve the extreme ballet positions, the external rotation, especially at the hip joint, is very important for ballet dance performance. Dancers who are limited in their range of motion at the hip often apply an additional external torque to the leg relative to the thigh and the foot relative to the leg. This may cause a foot pronation (*rolling in*) and subsequent hypermobility of the first ray. Then it ultimately leads to a loss of medial arch support of the foot [8], [10], [17]. Ex-

cessive use of this strategy results in pathologies, which could be integrated into the movement stereotypes, such as walking.

The results of our study showed significantly lower pressure peaks in the lateral edge of forefoot and in the midfoot in ballet dancers than in non-dancers. This results from the lower midfoot loading in ballet dancers according to the findings of Rodgers [2]. He observed the lower midfoot loading at a rigid foot with high arch. This can confirm the dancer's strategy of an effort to decrease the pronation position of the foot by supination muscular activity [10].

The results also showed significantly higher pressure peaks in the medial edge of forefoot in ballet dancers than in non-dancers. This finding shows higher immediate loading on the first ray, which can confirm the compensatory strategy of the lack of motion range as mentioned above. In agreement with our results are the findings of Hillstrom et al. [11] and Mootanah et al. [18]. They observed the higher medial arch loading at feet with hyperpronation. This failure of medial stability the dancers hold up the arch by active supination of the foot that allows an inversion of calcaneus, while maintaining the eversion of the forefoot relative to rearfoot. Thereby the stability of arch is reestablished [10].

Foot hyperpronation, which was observed in the present study in a group of dancers can cause the spread of pathology in disto-proximal direction throughout the body. So excessive pronation leads to excessive internal rotation of the tibia, knee valgus, internal rotation of the femur, pelvic anteversion resulting in lumbar hyperlordosis and is therefore a risk factor for many injuries of lower extremity and spine, especially from overuse [1], [8], [11], [19], [22]. Bryant et al. [23] noted that excessive foot pronation is an important etiologic factor in the development of hallux valgus, representing the most common deformity of the foot in ballet dancers.

As regards rearfoot our results reached significantly longer duration of the foot loading in both heel areas in ballet group. This results in significantly higher total rearfoot loading in the group of ballet dancers. These findings may indicate a relief from forefoot's persistent overloading in ballet shoes, which are unable to absorb shock and protect the underlying structures [8], [9], [24]. Walking in pointe shoes doubles the pressure peak acting on the foot compared to barefoot, during landing the load is up to 60 times higher [25]. These high pressures that impact the dancer's foot are strong predictor of the occurrence of pain, deformity and overuse injuries of ballet dancers' lower extremity and foot [26], [27].

Another factor which can influence pressure peak magnitudes is walking speed [28], however in our study average walking speeds in both groups are very similar, so we did not consider this variable.

Our results proved a significant relationship between a long-term and intense extreme demands of musculoskeletal system by dance and changes in plantar pressure distribution in ballet dancers. To understand the high incidence of injuries and deformities of the foot in the dancers it is necessary to understand the nature of ballet poses compensatory strategies and consequently their integration into movement stereotypes in more detail.

## 5. Conclusions

The results of the present study revealed significant differences in the plantar pressure distribution during the stance phase of gait between observed groups. The first conclusion was higher medial immediate loading of forefoot and lower midfoot and lateral loading in dancers in comparison with non-dancers. The second one was that the dancers had significantly longer duration of foot loading and consequently significantly higher total rearfoot loading. These findings showed that long-term and intensive dance practice influences dancer's gait stereotype. From this non-physiological foot usage, a variety of pathologies can originate, e.g. ankle sprain, stress fractures, deformities, etc. Therefore, we can conclude that the correct distribution of the body weight in foot axis is necessary for a successful prevention of its excessive inversion and eversion. We recommend to include the compensatory exercises as a part of daily training program, focused on the proper use of foot and leg and improve functional ankle stability.

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