THE INFLUENCE OF FOOT ALIGNMENT ON KINEMATIC PARAMETERS OF GAIT IN BALLET DANCERS

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The aim of this study was to assess the relationship between kinematic parameters and foot rotation relating to gait direction. Thirty-two professional ballet dancers (15 males, 17 females; age 26.8±5.6 years) participated in this research. Each participant performed five trials of gait at self-selected walking speed. Kinematic data was obtained using the optoelectronic system Vicon MX. Foot axis angle (°) was obtained by Footscan (RSscan International). Significant differences ($p < 0.05$) between the kinematic variables and foot axis angle were observed at knee flexion in the stance phase and ROM (range of motion) and maximum pelvic rotation in female as well as knee ROM in the frontal plane, and maximum pelvic obliquity and rotation in men. Significant differences between two groups of dancers with foot axis angle under and above 15 degrees were found for the knee and pelvic kinematic variables. This altered movement can lead to increased stress load on the joints of the lower limbs and predispose to injuries or early degenerative changes in the musculoskeletal system. Avoiding excessive foot external rotation during gait may reduce load on the musculoskeletal system and may prevent injuries.

KEY WORDS: gait, dance, foot axis angle, range of motion.

INTRODUCTION: Physical activities performed at high levels put great demands on the musculoskeletal system. In ballet, maintaining precise posture puts considerable stress on many segments of the dancer´s body and can significantly influence the mobility of the lower limb joints (Levinger et al., 2010). Previous studies have focused on the negative impact of sport activity on motor behaviour, supposing that frequent ballet training changes the pattern of stereotype movements. It leads to movement compensation and increases the risk of overuse injuries, predominately in the lower limbs (Gilbert, Gross, & Klug, 1998). However, the majority of ballet movements are performed with external rotation of the lower limbs (Kiefer et al., 2011; Wilson & Decker, 2009). Dancers can subsequently transfer it to gait performance. Therefore, altered joint alignment may be the result of excess external rotation of the lower limbs.
The aim of this study was to assess the relationship between kinematic parameters and foot rotation related to direction of gait.

METHODS: Thirty-two professional ballet dancers (15 males, 17 females; mean age 26.8±5.6 years; height 173.8±8.1 cm; weight 62.8±12.2 kg) from the ballet company of Mahen´s Theatre in Brno participated in this research. The exclusion criteria included any serious musculoskeletal pathology, severe pain or history of injuries or surgery to the lower limbs that may affect the results of this study. Kinematic data was obtained using the optoelectronic system Vicon MX (Vicon Motion Systems, Oxford, London). Reflective markers of kinematic model PlugInGait were placed at the pelvis and on the lower limbs. Foot axis angle (°) was obtained by Footscan (RSscan International, Olen, Belgium). Each participant performed five successful trials of gait at self-selected walking speed. Kinematic data was analysed and processed in the programmes Vicon Nexus and Vicon polygon, and the foot axis angle was analysed using the Footscan gait software.
Angle variables of the lower limbs and pelvis included peak values (defined as the maximum or minimum lower limb joint angle during selected gait phases) and the range of motion (ROM, defined as the difference between the maximum and minimum joint angle values). These angles were evaluated in all three planes. Foot axis angle (°) was defined as foot axis direction relating to gait direction. Dancers were divided in two groups relative to the

magnitude of the foot axis angle under and above 15 degree. The data was evaluated in Statistica (Version 9.0, Stat-Soft, Inc., Tulsa, OK, USA). Pearson´s correlation coefficient (r) was used to evaluate the relation of the magnitude of the foot axis angle to particular kinematic variables. The effect size η^2 was used for comparing the differences between these two groups of dancers. *P* values less than 0.05 were considered as significant.

RESULTS: Correlation coefficients of selected kinematic variables with foot axis angle in ballet dancers are shown in Table 1. Significant differences between kinematic variables and the foot axis angle were observed at knee flexion in the stance phase (p = 0.004) and ROM (p = 0.004) and maximum pelvic rotation (p = 0.025) in female, ROM knee in frontal plane (p = 0.003) and maximum pelvic obliquity (p = 0.026) and station (p = 0.028) in men. The differences between two groups of dancers relative to the magnitude of the foot axis angle under and above 15 degree are shown in Table 2. The large effect size was found at knee flexion during stance (η^2 = 0.425), knee extension during swing (η^2 = 0.394) as well as maximum pelvic obliquity (η^2 = 0.500) and rotation (η^2 = 0.401) and ROM of pelvic rotation (η^2 = 0.600).

Table 1.
Correlation coefficients and significant differences between kinematic variables and foot axis angle in dancers

	Men			Female		
Variables	Mean	SD	*r*	Mean	SD	*r*
Foot axis angle	18.89	7.09		17.89	5.60	
Knee flexion during stance	13.99	5.42	0.132	17.30	5.51	-0.485*
Knee extension during stance	2.66	2.97	0.109	2.27	2.90	0.027
Knee flexion during swing	64.08	4.37	-0.011	65.35	3.39	0.013
Knee extension during swing	0.85	4.36	-0.125	2.12	3.61	0.186
Knee adduction	15.27	11.25	0.279	3.87	7.16	0.201
Knee abduction	-1.82	7.94	-0.026	-9.01	8.02	0.256
ROM knee in frontal plane	17.09	5.80	0.549*	12.88	4.45	-0.141
Knee internal rotation	4.94	7.19	-0.056	6.21	11.01	0.060
Knee external rotation	-17.88	7.63	-0.153	-16.47	9.37	0.052
ROM knee in transversal plane	22.82	5.88	0.141	22.69	8.03	0.021
Pelvic retroversion	1.45	5.52	0.163	0.13	4.38	-0.105
Pelvic anteversion	5.33	5.35	0.217	4.02	4.42	-0.025
ROM of pelvic tilt	-3.95	1.27	-0.299	-3.56	1.18	-0.099
Minimum of pelvic obliquity	-4.74	4.60	0.212	-6.36	2.79	-0.024
Maximum of pelvic obliquity	3.54	3.80	0.429*	5.02	3.06	0.045
ROM of pelvic obliquity	-8.28	2.23	-0.311	-11.30	3.28	-0.048
Minimum of pelvic rotation	-5.44	4.66	0.137	-6.49	4.54	-0.067
Maximum of pelvic rotation	5.50	4.81	0.423*	5.45	4.68	0.390*
ROM of pelvic rotation	-10.84	3.96	-0.365	-11.93	4.40	-0.483*

r - Pearson´s correlation coefficient, * statistically significant differences (p < 0.05), ROM - range of motion

Table 2.
The effect size between two groups of dancers relative to the foot axis angle

	Foot axis angle <15°		Foot axis angle >15°		
Variables	Mean	SD	Mean	SD	η^2
Knee flexion during stance	17.46	5.80	14.83	5.43	0.425#
Knee extension during stance	2.01	2.49	2.70	3.14	0.146
Knee flexion during swing	64.95	3.98	64.68	3.87	0.058
Knee extension during swing	0.43	3.13	2.20	4.31	0.394#
Knee adduction	7.76	8.67	9.76	11.91	0.131
Knee abduction	-6.18	7.50	-5.52	9.43	0.059
ROM knee in frontal plane	13.94	3.65	15.28	6.31	0.149
Knee internal rotation	5.60	8.80	5.64	9.82	0.050
Knee external rotation	-17.41	7.62	-16.95	9.16	0.054
ROM knee in transversal plane	23.01	6.60	22.60	7.40	0.056
Pelvic retroversion	0.08	3.33	1.15	5.71	0.131
Pelvic anteversion	3.62	3.35	5.25	5.55	0.249
ROM of pelvic tilt	3.54	1.10	3.87	1.29	0.176
Minimum of pelvic obliquity	-5.99	2.37	-5.37	4.46	0.096
Maximum of pelvic obliquity	3.23	2.66	4.98	3.77	0.500#
ROM of pelvic obliquity	9.22	1.82	10.28	3.76	0.246
Minimum of pelvic rotation	-5.89	2.77	-6.06	5.43	0.052
Maximum of pelvic rotation	4.18	2.97	6.25	5.38	0.401#
ROM of pelvic rotation	9.94	2.75	12.30	4.68	0.600#

η^2 - effect size, # large effect size ($\eta^2 > 0.26$)

DISCUSSION: The magnitude of foot axis angle influenced the alignment of some kinematic variables in ballet dancers. Increased external rotation of the foot (>15°) is associated with decreased knee flexion during loading response and increased knee extension at heel strike. Due to the association of joint coupling, external rotation of the foot is commonly associated with external tibia torsion. This may cause early strain of the passive knee stabilizer during the stance phase, limiting greater movement at this joint. Results also demonstrate significant increase in maximum pelvic obliquity, maximum pelvic rotation and ROM of pelvic rotation. In ballet dance, foot position in external rotation and pronation is required (Clipinger, 2007; Lung et al., 2008). This foot position during the gait cycle reduces pelvic stability (Barwick et al., 2012). Ahonen (2008) described that these changes in performance of gait in the frontal plane relate to foot alignment. This leads to pelvic drop with adduction of the knee during single leg weight bearing. Additionally, gait with lower limbs in external rotation leads to greater medial load at the knee joint, which can predispose to injury (Cimelli & Curran, 2012; Clippinger, 2007) or degenerative changes of the joint (Rusell & Hamill, 2010).

CONCLUSION: Our results confirm that foot axis angle influences particular kinematic parameters of gait in ballet dancers. These findings support that ballet dancers have the tendency to transfer the adjustment of increased foot external rotation, which commonly occur in ballet movements, to the performance of gait. The increased foot external rotation changes mainly the alignment of the knee and the pelvis. Altered knee movement results in failure to absorb the forces applied to the lower limbs during the gait cycle. It can lead to increased stress on the lower limb joints and predispose to injuries or early degenerative changes. Avoiding increased foot external rotation during gait should be the necessary part

of comprehensive care of dancers in order to reduce musculoskeletal load and prevent injuries.

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