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The influence of ballet shoes in elementary ballet jumps.

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KEY WORDS:

Inverse Dynamics. Dance. Injuries.

ABSTRACT

Jumps are one of the most important elements that compose each training practice and performances, being repeated during the whole life of a dancer. The purpose of this study was to access the internal dynamics of some balletic movements, and to analyze the influence of different types of ballet shoes, in the generation of joint forces, mechanical work and power, during the landing phase of ballet jumps. Seven ballet dancers performed different jumps, with two types of ballet shoes. Performances were videotaped and reaction forces were recorded. Ankle and knee joint forces and muscle mechanical work were estimated using an inverse dynamics approach. The main results showed that different types of ballet shoes can affect in some jumps, the joint resultant forces. Nevertheless, different types of ballet shoes seem not to affect the muscle mechanical work production. It was possible to observe that, the values obtained in some jumps, are in order of three times the body weight, showing the injury potential that the anatomical structures of ballet dancers are exposed to. In summary different ballet shoes affect joint forces but do not affect negative mechanical work, being dependent on the technique used to perform the jump.

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Influência dos sapatos de *ballet* nos saltos básicos do *ballet*.

RESUMO

Na dança clássica, os saltos constituem um dos elementos mais importantes e usuais nas rotinas de treino dos bailarinos, sendo repetidos inúmeras vezes nas suas práticas. O objetivo do presente estudo foi o de determinar a dinâmica interna de alguns movimentos do *ballet* clássico e analisar a influência do uso de diferentes tipos de sapatos na produção de força articular, trabalho e potência mecânica, durante a fase de amortecimento ou receção, de saltos elementares do *ballet* clássico, nomeadamente o *sauté en cou-de-pied*, o *glissade jéte* e o *grand jéte*. Sete estudantes de *ballet* realizaram aleatoriamente os diferentes saltos com dois tipos de sapatos: as usuais sabrinas de couro e tecido e os sapatos de pontas. As *performances* foram registadas em vídeo e as forças de reação do solo recolhidas através de uma plataforma de forças. As forças articulares do tornozelo e do joelho, assim como o trabalho muscular mecânico, foram estimados utilizando a técnica de dinâmica inversa. Os principais resultados sugerem que a utilização dos diferentes tipos de calçados podem afetar, em algum dos saltos selecionados, as forças articulares resultantes. Contudo, diferentes tipos de sapatos parecem não afetar o trabalho muscular mecânico produzido. Observou-se que os resultados obtidos em alguns saltos são da ordem das três vezes o peso corporal dos sujeitos, mostrando desta forma o potencial lesivo a que as estruturas anatómicas dos bailarinos estão expostas. Os diferentes sapatos estudados afetaram as forças articulares calculadas, no entanto não afetaram o trabalho mecânico negativo, sendo este muito dependente da técnica utilizada na *performance* do salto.

PALAVRAS CHAVE:

Dinâmica inversa. Dança. Lesões.

INTRODUCTION

In classical ballet, as well as in other forms of dance and sports, jumps are one of the most important elements that compose each training practice and each performance, being repeated constantly during the whole life of dancers and athletes. According to Liederbach et al. (11), classical ballet dancers perform more than 200 jumps per 1.5-hour daily technique class, more than half of which involve single-leg landing. In sports, it is well demonstrated that the magnitude of forces produced during some jump performances can exceed largely the subject's body weight. In dance, little research has been done to insure the biomechanical demands of movements that may be related to injury. Nevertheless, some studies confirm a relationship between the amplitude of movements and the magnitude of joint forces during jumps, recognizing the potential damage consequences to the tissues involved in its dissipation (17, 19, 21). Injuries of the lower extremities are very often among dancers, and have been discussed widely (7, 8, 13, 14, 16, 17, 18). Approximately 86% of these injuries are reported to ballet dancers and have especial incidence in the lower limb. Due to the nature of their movements, which involves unusual amplitudes of movement, unusual joint positions, and muscular efforts with excessive impact forces, it is well accepted the significant devolution of anatomical structures, like bone tissue, tendons, ligaments, and others (20, 21). According to Simpson et al. (20, 21), the repetitive axial and shear forces, combined with the speed of applied loading, are involved in the etiology of injuries, namely the osteoarthritis. According to Hardaker et al. (8) and Schon, and Weinfeld (18), deficient technique of dancers, associated, for example, to improper landings used to set down from the aerial movements, can also be related to injury tendency. Another factor that also influences the increased impact forces during movements is the interface between the body and the ground. Some studies have demonstrated the influence of the use of different shoes on the amount of joint reaction forces produced in the lower limb during different movements (3, 6, 10). The centenarian special design and manufacture characteristics of the ballet shoes are considerably harder and strong in order to accommodate the technical demands of the dancer's foot. According to Lin et al. (12), the high injury rate and the threatening consequences for ballet dancers, provide an important clinical demand for the identification of the risk factors and to develop preventive strategies for injuries. A proper biomechanical evaluation, risk assessment, and prevention-oriented treatment are necessary to minimize future problems and promote a full and lasting recovery when an injury is sustained (17).

Besides the kinematic and kinetic analysis, the study of the energetics involved during some movements, could be well representative of the technical demands selected in the movements performance. The energy transfer among muscles and segments can be estimated by the muscle mechanical work produced and this will be very useful to understand the influence of the individual technique strategy followed by dancers in the generation and absorption of impact forces during landing movements.

Therefore, the purposes of the present study were: (a) to analyze the influence in the use of different types of ballet shoes (pointe shoes and leather slippers shoes), in the ankle and knee joint forces; (b) to analyze the influence in the use of different types of ballet shoes in the knee and ankle muscle mechanical work; (c) to analyze the influence of different ballet jumps in the ankle and knee joint forces and in the muscle mechanical work.

MATERIAL AND METHODS

SUBJECTS AND EXPERIMENTAL PROCEDURE

Seven female ballet dancers (16.1 ± 4.1 years old, 45.4 ± 5.9 kg, 160.0 ± 4.0 cm), with more than ten years of daily practice in classical ballet participate in the study. None of the dancers present, until the moment, any kind of injury that could influence the performance of the jumps. The study was approved by the Ethics Committee, and is in accordance with Harriss and Atkinson [(9)].

The ballet jumps selected were: Jump 1 - *sauté en cou-de-pied*, Jump 2 - *glissade jéte*, and Jump 3 - *grand jéte*. In classical ballet, jump 1 is classified as a small jump, and due to technical demands must be performed in the same place with a maximum vertical displacement of whole body. This jump was recorded in three sets of five consecutive jumps performed successively by each dancer. Only the first four repetitions were considered for analysis. The jump was performed always with the take-off and the landing phases on a force plate. Jump 2 is classified as a medium jump, with a small horizontal displacement before the take-off phase, followed by a maximum vertical displacement of whole body. Finally, jump 3 is technically considered as a large jump preceded by a great horizontal displacement before the take-off phase, followed by a maximum horizontal and vertical displacement with a full leg splits through the air. Jumps 2 and 3 were performed three times each one and only the landing phase was performed on the force plate. Table 1, presents a description of the three jumps (mean and SD) relative to jump height, knee and ankle range of motion (ROM) and knee and ankle acceleration.

TABLE 1 — Average (and SD) values for height jump, knee and ankle range of motion (ROM) and knee and ankle acceleration (accel), in Jump 1, 2 and 3.

VARIABLE	JUMP 1	JUMP 2	JUMP 3
Jump height (m)	0.20 (0.01)	0.33 (0.02)	0.54 (0.06)
Knee ROM (degrees)	56.33 (6.43)	52.67 (3.06)	63.33 (10.41)
Knee accel (degrees/ s^2)	261.67 (37.53)	211.67 (48.56)	225.00 (44.44)
Ankle ROM (degrees)	96.67 (5.77)	98.00 (4.00)	82.67 (4.04)
Ankle accel (degrees/ s^2)	121.67 (23.63)	82.00 (13.86)	81.67 (20.82)

After a short warm-up, which was individually selected by the ballet dancers, subjects were familiarized with the experimental procedures for data collection. The jumps were performed with pointe shoes and leather slippers in a random order.

A classical inverse dynamics approach was used to estimate the intersegmentar forces and moments, assuming a bidimensional model of the lower limb with three rigid segments: the thigh, the shank, and the foot [(1)]. The joints were assumed to be point like (hinge joints). The angular and linear kinematic variables were obtained using the Peak Performance Analysis System at a sample frequency of 120 Hz. The optical axis of the camera was perpendicular to the plane of motion of the limb. Segments were delimited with reflective markers over the centre of rotation of the *trochanter* major, the lateral *femoral epicondyle*, the lateral *malleolus* and the fifth metatarsal head. Ground reaction forces were measured using an AMTI force plate, with a sample frequency of 1000 Hz. The anthropometrical variables: mass and center of mass of each segment, were obtained from the tables proposed by Clauser and colleagues [(2)] and the moment of inertia, by the data proposed by Dempster [(4)]. The muscle mechanical power [(5)] was calculated using the joint moments and the angular velocity of each joint. The muscle mechanical work done in a given period of time was obtained from the integration of mechanical power.

STATISTICAL ANALYSIS

The results were analyzed through statistical procedures, firstly applying a normality test (Kolmogorov-Smirnov). The comparisons of the values of forces with different ballet shoes were made using *paired t-test*; the comparisons among different jumps were made with a two-way ANOVA with repeated measures, and a *post-hoc* Tukey-b test. The values of muscle mechanical work for all the comparisons were made using a Wilcoxon test. The probability level accepted for statistical significance was $p<0.05$.

RESULTS

Figure 1 was constructed to give a representative example of the estimated values of knee joint forces (% BW), during the performance of a set of jump 1, performed using LS. Based on the peak values and time duration of the jumps, it is possible to observe a similar performance pattern during the successive five repetitions of the jump. Similar results were observed in the ankle joint, in all attempts, and in all subjects, demonstrating a high consistence of the results obtained.

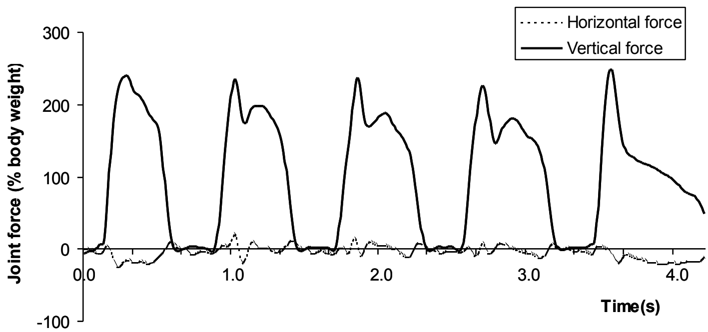

FIGURE 1 — Estimated values of knee joint force (%BW) during the execution of Jump 1 with LS shoes.

Figures 2 and 3 shows representative examples of the estimated values of knee joint moments and muscle mechanical power, respectively, produced in the knee joint during the performance of jump 1. The instant in time in which the resultant extensor moment is maximum (absolute value) and the mechanical power is null (the angular velocity is zero), correspond to the instant where a maximum flexion of the lower limb was reached, i.e., the landing phase of the jump.

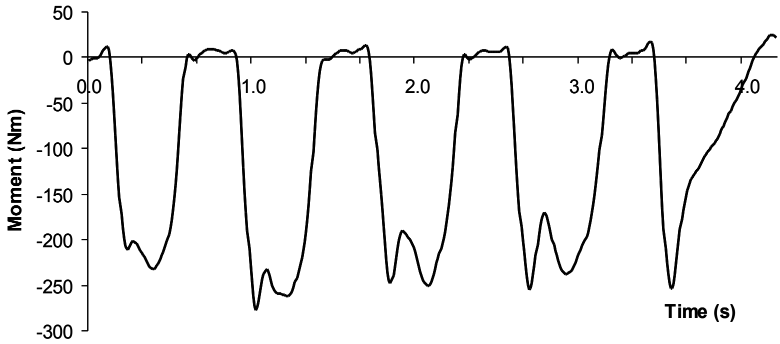

FIGURE 2 — Estimated values of knee joint moments produced during the execution of Jump 1. The positive values of moment indicate resultant flexor moments and the negative values of moment indicate resultant extensor moments.

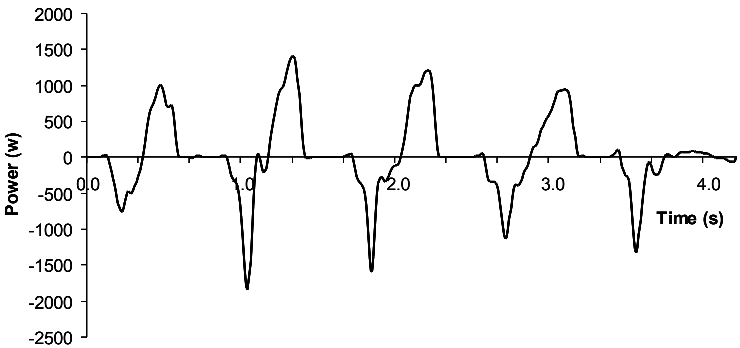

FIGURE 3 — Estimated values of muscle mechanical power produced around the knee joint.

Table 2 show the estimated peak values of ankle and knee joint resultant forces (%BW), in each ballet dancer using PS and BS, during the performance of Jump 1, 2, and 3. Only Jump 2 showed significant differences comparing PS with LS. The highest values of ankle and knee joint forces were measured using PS. In the comparison among jumps, the ankle and knee joint forces obtained in Jump 3 were significantly higher than the others, independently of using PS or BS shoes.

TABLE 2 — Average (and SD) values of the ankle and knee joint forces normalized to BW, during the performance of Jump 1, Jump 2, and Jump 3 with pointe shoes (PS) and leather slippers shoes (LS).

JOINT FORCE (% BW)	ANKLE		KNEE	
	PS	LS	PS	LS
Jump 1	254 (25)	253 (30)	238 (43)	227 (32)
Jump 2 *	266 (20)	241 (20)	253 (27)	225 (12)
Jump 3 **	284 (43)	308 (60)	368 (144)	301 (59)

(*) significant differences between PS and LS, in the ankle and knee joints; (**) significant differences from the other jumps, using PS and LS, in the ankle and knee joints.

Table 3 shows the values of negative muscle mechanical work (NMW) estimated in the ankle and knee joint during the performance of Jumps 1, Jump 2, and Jump 3 with PS and LS. The NMW represents the work done in the eccentric phase of the jumps. In jump it's possible to observe, that there was a significant difference between the knee and the ankle joints, regardless the PS or the LS. In Jump 3, there was a significant difference only in the use of PS. The higher values of NMW were reached always in the knee joint. When the jumps were compared between them, the ankle joint showed significant differences in NMW in all jumps, independently on the ballet shoe. On the knee joint using LS, significant differences were found between Jump 2 and the other jumps. Comparing jump 1 and 2, significant differences in NMW were found with PS. Comparing jump 2 and 3, significant differences in NMW occurred when using the LS.

TABLE 3 — Average (and SD) values of the ankle and knee joint forces normalized to BW, during the performance of Jump 1, Jump 2, and Jump 3 with pointe shoes (PS) and leather slippers shoes (LS).

NMW (J)			
		Ankle [b]	Knee [c, d, e]
PS	Jump 1 [a]	-58 (14)	-90 (20)
	Jump 2	-111 (20)	-121 (27)
	Jump 3 [a]	-80 (25)	-113 (49)
LS	Jump 1 [a]	-55 (31)	-86 (44)
	Jump 2	-97 (24)	-104 (47)
	Jump 3	-79 (31)	-85 (46)

(a) significant differences between ankle and knee joints; (b) significant differences among all jumps independently on the ballet shoe; (c) significant differences between jump 2 and the other jumps using LS; (d) significant differences between jumps 1 and 2 using PS; (e) significant differences between jumps 2 and 3 using LS.

DISCUSSION

The knowledge of intra-articular forces is very important to understand the risk of injuries associated to repetitive efforts and his eventual prevention. The resultant joint forces allow the evaluation of the landing impact forces. As it is possible to observe, and with exception to jump 3, the average values of the ankle and knee joint forces decrease as we move upwards into the body, i.e., the ankle force is larger than the knee force. This decrease of force from one joint to another is probably related to the dissipation of energy provided by the muscles involved in the movement, and the lower mass located above the considered joint. Based on the literature [22], high skeletal loading intensity has been defined as ground reaction forces greater than four times the body weight. As it's possible to observe in table 2, the mean values obtained in jump 3 are in order of 3.5 times the body weight, however some ballet dancers reached values around six times the body weight. According to Simpson and Kanter [20], forces at the knee joint during some dance jump landings have been measured to exceed 12 times body weight. Because in ballet dance during each training practice and each performance, movements are constantly repeated, the incidence of overload injuries is pronounced [19, 20, 21]. Even only in jump 2 significant differences comparing PS with LS were observed in the joint forces, the use of PS showed a tendency for higher values than with LS. The hardness of the material used in the manufacture of PS is probably responsible for this propensity, determining a lower energy dissipation. In the comparison among jumps, the ankle and knee joint forces obtained in Jump 3 were significantly higher than the others, independently of using PS or BS shoes. The motion analysis considering joint moments and muscle power is very important in human locomotion, since it reflects the neuromuscular strategies used by the subject and allows a novel comprehension about the individuality used in the performance of the movements, eventually allowing an intervention in the technical level, and is directly related to the efficiency of the movement [15, 23]. Unperceived differences in performance through a visual inspection are very clear looking at these parameters. Ankle and knee NMW comprises the muscle effort (eccentric phase) around these joints and is highly correlated with the technique used on the landing phase of the jumps. With few exceptions, similar results around the knee and ankle joints were observed, suggesting an uniform distribution of the impact absorption in these joints. In cases where there were significant differences, the higher values were always presented in the knee joint. No differences were found in NMW, when comparing the two kinds of ballet shoes, during the performance of the three ballet jumps selected for the study. Results suggest that probably other differences could be more evident if another joint, like tarsal-metatarsal joint was observed. According to the present study, it seems evident that this kind of approach is especially important for the study of the contact forces and consequent joint tissue injury.

In summary, the results of the present study highlight, that different kinds of ballet shoes can affect in some jumps, the joint resultant forces. In another way, different kinds of ballet shoes seem not affect the muscle mechanical work production. Relatively to each jump, resultant joint forces were higher in Jump 3 than in the other jumps, reaching in some cases values around six times the body. Through the analysis of the magnitude of the values from joint forces estimated in the ankle and knee joints, it was possible to observe the injury potential that the anatomical structures of ballet dancers are exposed to. As expected, and with few exceptions, the average values of the ankle and knee joint force decreases as we move upwards into the body, i.e., the ankle joint force is larger than the knee joint force. This decrease of force from one joint to another joint is possibly due to the occurrence of absorption phenomenon's induced by the body tissues. This occurrence will put in perspective the energy transfer phenomena processed by the bi-articular muscles, subsequently presented in a future approach (the hybrid forward-inverse dynamic model).

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