BIOMECHANICAL APPROACH TO BALLET MOVEMENTS: A PRELIMINARY STUDY

Andreza P.Picon[1], Paula H.Lobo da Costa[1,4], Filipa de Sousa[2], Isabel de C.N.Sacco[3,4] and Alberto C. Amadio[4]
[1]Departamento de Educação Física e Motricidade Humana, UFSCar, SP - Brazil
[2]Faculdade de Educação Física e Ciência do Desporto, Porto, Portugal
[3]Departamento de Fisioterapia, Fonoaudiologia e Terapia Ocupacional, FM USP, SP - Brazil
[4]Laboratório de Biomecânica, EEFE USP, SP - Brazil

Movements in ballet dance often involve extreme joint positions and muscular efforts that may exceed normal ranges of motion and generate high stresses on bone and soft tissues. The primary aim of this study was to apply the principles and techniques of biomechanics to study ballet movements. Ground reaction forces and plantar pressure distribution were registered with a Kistler Platform and a Tekscan Systems respectively. Knee joint action in the sagittal plane was simultaneously collected with an electrogoniometer. Peak vertical forces, peak pressures and knee flexion-extension were analyzed and discussed. A better understanding of these biomechanical aspects may lead to a decrease of the injury risks and also to more graceful and efficient dance movements.

KEY WORDS: biomechanics, plantar pressure, ground reaction force, ballet dance

INTRODUCTION: The majority of biomechanical studies have not concerned classic ballet movements. In the scientific literature, authors make reference to dance in terms of applied anatomy and sports medicine and have explained little about the actual biomechanical aspects of ballet dancing. Medical studies have been showing the high incidence of morphological and physiological alterations of ballet dancers' feet due to the *pointe* shoe (Miller *et al*., 1975). The feet and the ankle are the body areas more frequently injured in ballet dancers (Quirk, 1983) and Sammarco & Miller (1982) have discussed the poor protection that the *pointe* shoes provide to the dancer's feet. One of the most extreme positions during the ballet movements is to stand *en pointe* which demands great support by extreme plantar flexion. The longitudinal medial, lateral and transverse plantar arches are directly involved in the support of the extreme plantar flexion during standing *en pointe*, especially the longitudinal lateral arch that is responsible for sustaining the position.

Besides the extreme usage of the plantar arches to support body weight while standing *en pointe*, the superior talar tubercle of the heel is subjected to high peak pressures due to the continuous and exaggerated foot position. These unusual pressures lead to innumerous pathological consequences, such as calcifications and much pain (Hardaker & Moorman, 1984).

The first *pointe* shoe was constructed during the romantic epoch (1750 – 1850), when people considered the woman an ethereal being and conceptualized standing *en pointe* as representing the lightness of a nymph. The classic *pointe* shoe did not receive the same attention as the sport shoes did in the biomechanical scientific literature. The field of biomechanics could provide an important theoretical and methodological understanding of the overload during classic ballet dance. It is known that an alignment of two degrees is sufficient to relieve the load in the ankle by as much as 18 kg, or up to 25 to 30% of an adult dancer's weight. Teitz *et al.* (1985) found high peak plantar pressure while the dancer stood *en pointe* using the *pointe* shoe, especially under the first and second metatarsal heads.

More biomechanical studies in the field of ballet are needed to describe the mechanical loads of the locomotor apparatus and to lessen the incidence of injuries related to these movements. The structure of the ballet *pointe* shoe also needs to be better understood because of its probable contribution to the high incidence of injuries.

The purpose of the present paper was to study ground reaction forces and peak plantar pressure during the following classic dance movements: *saute, grand jeté*, and standing *en point*. The *saute* is a vertical leap taking off and landing with both feet. The *grand jeté* is a broad leap off of one foot, keeping both legs extended and spread in the anterior-posterior direction during flight, with landing on the other foot.

METHODS: Ground reaction forces were measured by a piezoelectrical force platform (Kistler Instruments). The ground reaction force variables and the joint angular variation were collected and sampled at 1000 Hz for periods of three seconds (s). The knee joint angular variation was measured by a planar electrogoniometer (elgon). The elgon bars were fixed over the thigh and leg using elastics strings, so that the potentiometer was located in the estimated geometric center of the knee joint. Since planar angular variation of the knee joint was registered, only flexion–extension movements were analyzed. While positioned on the force platform, the dancer performed three trials (T-1, T-2 and T-3) of five consecutive *saute* from the first and fifth ballet positions, and three trials of *grand jete*. Plantar pressure distribution was also studied. The *F-Scan insoles (*Tekscan, Inc*.)* were used to collect peak pressure at 50 Hz for periods of eight seconds of standing *en pointe*. The *F-Scan mat* was used to collect peak pressure of *saute* from 1st position at 165 Hz for periods of 4.3 seconds. The dancer was requested to stand over a mat and performed ballet *saute* for 4.3 seconds. Also, the dancer stood for eight seconds *en pointe* while wearing *pointe* shoes with the system insoles inside. Depending on the movement analyzed, peak pressures were evaluated in the selected plantar areas: all toes (standing *en pointe*), halux (saute); forefoot (metatarsal heads – *saute* and standing *en pointe*) and heel (*saute* and standing *en pointe*). The results of only one ballet dancer are presented. The subject was a 23-year-old female classic ballet teacher, with more than eight years of practice. She had a mass of 54 kg and a height of 1.67 m, and had no history of musculoskeletal injuries. The quantitative results of the selected variables are presented in terms of mean values, standard deviations (sd) and coefficient of variation (CV).

RESULTS: The preliminary results of the ground reaction forces were concerned with three ballet movements: *grand jete, saute* from 1st postion and *saute* from 5th position. While positioned on the force platform, the dancer performed three trials (T-1, T-2 and T-3) of five consecutive *saute* from the first and fifth ballet positions, and three trials of *grand jete*. The first and the last peak magnitudes of the vertical ground reaction force components were not included for analysis because of the initiation and termination character of these curves. As is shown in Table 1 and Figures 1 and 2 below, the peak magnitudes of the vertical ground reaction forces varied from four to five times body weight for these movements. The greatest vertical forces were generated during *saute* from 1st position, followed by the *saute* from 5th position and the *grand jete.*

Table 1 Peak magnitudes of the vertical component of the ground reaction forces (in body weight - BW) during *grand jete*, *saute* from 1st , and *saute* from 5th positions

	Grand jete	Saute 1st pos.	Saute 5th pos.
n	3	15	15
Mean ± sd (BW)	4.52±0.15	5.26±0.41	4.60±0.22
CV (%)	3.32	7.79	4.78

In studying the results of the ground reaction forces, the external load applied to the body and the peak forces of these ballet movements were considered to be of the same magnitude as for depth jumping, usually used in strength training programs. The peak forces were coincident in time with the peak flexion angle of the knee, and the knee started flexing before floor contact, probably in preparation for impact. Thanks to the mechanical characteristics of the muscular tissue, this knee flexion represented a strategy to protect the locomotor apparatus from very high impact forces experienced during the landing phase of these movements. The differences in foot positions, i.e., 1st position vs 5th position, during the propulsion phase of the jumping movements in ballet are considered by dancers as an important factor influencing the performance. Apparently, these differences also influenced the magnitudes of the peak reaction forces produced by the dancer, and thus, the loads on the locomotor apparatus.

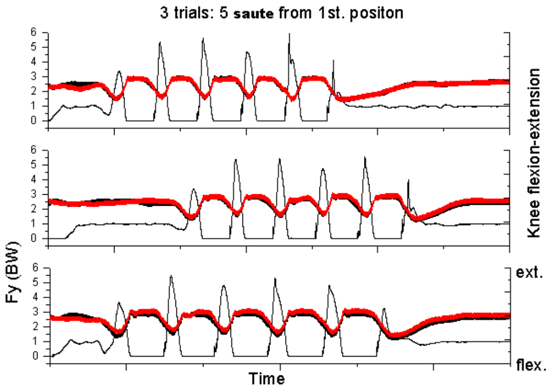

Figure 1 - Vertical ground reaction forces and knee flexion-extension movements during saute from 1st position. Forces are in BW and flexion-extension are in arbitrary units. 3 trials with 5 successive *saute* are represented.

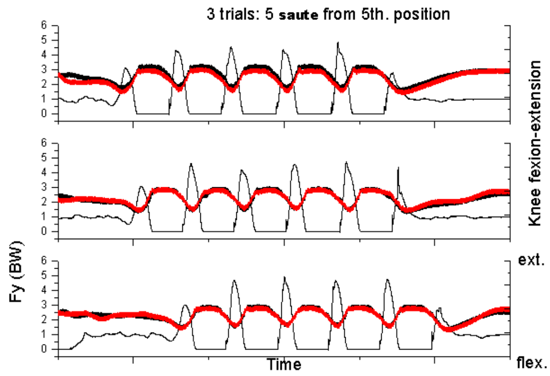

Figure 2 - Vertical ground reaction forces and knee flexion-extension movements during saute from 5th position. Forces are in BW and flexion-extension are in arbitrary units. 3 trials with 5 successive *saute* are represented.

The preliminary results of peak pressures are concerned with two ballet movements: *saute* from 1st postion and standing *en pointe*. The dancer performed two trials of ten consecutive *saute* from the 1st ballet position over a pressure mat and one trial of 8 seconds standing *en pointe* using the F-Scan insoles. As is shown in Tables 2 and 3 below, the peak pressure over plantar areas were higher for the halux and for the forefoot which includes the toes except the halux. The peak pressure over the heel was much less than other areas because this part of the foot was not in contact with the floor during *saute*. According to Table 2, greater CV was found for the heel area during *saute*, and this could be due to the variability of the support time and the contact area in each *saute*.
As shown in Table 3, during standing *en pointe*, peak pressure over the toes was higher than over the forefoot. These findings showed that the toes and the metatarsal heads were the most compressed plantar areas during these ballet movements. The results were in keeping with the fact that there are higher incidence of injuries in anterior parts of the foot. Comparisons of both movements showed that short jumps (*saute*) produce greater peak pressure and, consequently, higher loads over the anterior part of the foot. Considering the anatomy of the foot, the values obtained during these movements over specific plantar areas are considered above the limit to produce tegument lesions (Mueller, 1992). Duckworth *et al*. (1985) as well as Mueller (1992) discussed the fact that peak plantar pressure above 1 MPa during dynamic tests should be interpreted with caution since these values are very extreme for the skin tissue of the foot.

Table 2 Mean, standard deviation and coefficient of variation (CV) of peak pressure over three plantar areas (kPa) (forefoot, halux and heel) during *saute* from 1st position (n=20)

	Forefoot		Halux		Heel	
	Right	Left	Right	Left	Right	Left
Mean ± sd (kPa)	937.3±171.3	596.9±146.5	609.3±182.7	519.7±94.1	252.5±247.6	150.6±195.1
CV (%)	18.3	24.6	29.9	18.1	98.0	129.5

Table 3 **Mean, standard deviation and coefficient of variation (CV) of peak pressure over fourplantar areas (kPa) (toes, forefoot, midfoot and heel) during standing *en point***

	Toes		Forefoot		Midfoot		Heel	
	Right	Left	Right	Left	Right	Left	Right	Left
Mean (kPa)	206.6±44.2	306.2±71.1	150.8±7.3	177.3±42.9	60.3±34.9	61.0±10.5	49.5±10.7	43.8±11.1
CV (%)	21.4	23.2	4.8	24.2	57.9	17.2	21.6	25.4

CONCLUSION: It was clear from studying the vertical forces, that the ballet dancer is submitted to very high external loads when wearing the *pointe* shoe. Standing *en pointe* did not produce very high and pathological peak plantar pressure, but it showed that the anterior parts of the foot are the most overloaded area during this ballet position. The footwear is probably one of the most influential factors on the mechanisms of ballet injuries; thus its contribution must be precisely known. These movements are repeated many times in a standard ballet routine, and therefore, it is important to gain some insights about the extent of the loads related to classic ballet. The *pointe* shoes associated with specific ballet movements may cause significant injuries with time and training, because they are not designed to protect against physical stresses. This study raised some questions: Can a properly designed *pointe* shoe reduce the forces and pressures experienced during ballet dancing? Can long-term preventative training reduce the incidence of ballet injuries?

REFERENCES:

Duckworth, T., Boulton, A.J.M., Betts, R.P., Franks, C.I., & Ward, J.D. (1985). Plantar pressure measurements and the prevention of ulceration in the diabetic foot. *Journal of bone and surgery*, **67-B**, 79-85.

Hardaker, W.T., & Moorman, C. T.III. (1986). Foot aand ankle injuries in dance and athletics: similarities and differences. In: Shell, C.G. (ed.). *The 1984 Olympic Scientific Congress Proceedings: the dancer as athlete,* Champaign, Human Kinetics, **8**, 31-41.

Miller, E.H., Schneider, H.J., Bronson, J.L., & McLainid, D. (1975). A new consideration in athletic injuries: the classical ballet dancer. *Clin. Orthop*., 111-181.

Muller, M.J. (1992). Etiology, evaluation, and treatment of neuropathic foot. *Critical Reviews in Physical and Rehabilitation Medicine*, **3**, 289-309.

Quirk, R. (1983). Ballet injuries: the Australian experience. *Clin. Sports Med*. 507-14.

Sammarco, G.J., & Miller, E.H. (1982). Forefoot conditions in dancers; part I. *Foot and Ankle*, **3**, 85-92.

Teitz, C.C., Harrington, R. M., & Wiley, H. (1985). Pressures on the foot in pointe shoes. *Foot and Ankle*, **5**, 216-21.