

**BIOMECHANICAL APPROACH TO BALLET MOVEMENTS:
A STUDY OF THE EFFECTS OF BALLET SHOE AND MUSICAL BEAT
ON THE VERTICAL REACTION FORCES**

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Ballet movements can be the focus of biomechanical studies in order to better understand the characteristic mechanical loads of the locomotor apparatus related to classic dance. "Pointe shoes" have been associated to high incidence of morphological and physiological alterations of ballet dancer's feet, however its contribution to injury mechanisms must still be precisely known. On the other hand, movements like jumps and leaps are frequently repeated in a standard ballet training, where the musical beat also plays a role on the motor behavior and its mechanical aspects. Therefore the purpose of the present study was to describe ground reaction forces during the "saute - 1st position" under the influence of footwear (slippers and pointe shoes) and musical beat in order to identify the relative contribution of these factors on the external loads measured. It was observed that the musical beat played a greater role on the ground reaction force magnitudes than the footwear.

KEY WORDS: ground reaction forces, classical dance, ballet jump.

INTRODUCTION: Ground reaction forces can be considered as the external loads applied to the body. A previous study (PICON et al., 2000) revealed peak vertical forces during the grand jete, saute - 1st and 5th position of the same magnitude as for depth jumping (varying from 4,5 to 5,2 times body weight). It was clear from the vertical forces that the ballet dancer is submitted to very high external loads, when performing with pointe shoes. The scientific studies of dance have focused mostly on applied anatomy and medical aspects (QUIRK, 1983; 1986; SAMMARCO & MILLER, 1982). More recently, biomechanical studies have tried to explain the loading characteristics of ballet dancing, due to the pointe shoes and the extreme positions of the foot while standing en pointe (TREPMAN, et al., 1998; TUCKMAN et al., 1991). Of great importance to the overall ballet performance is also the influence of musical beat, responsible for the speed aspect and thus the correct dynamic of the dance movements. Thus the mechanical loads over the locomotor apparatus during the performance of ballet movements can also be influenced by the beat identified by the time signature of the musical tempo and this aspect should also be considered while studying the ground reaction forces. The purpose of this study was to describe the external loads during a ballet movement, sauté - 1st position, while performed with two different footwears (slippers and pointe shoes) and two different time signatures (2/4 and 6/8) in order to identify the relative contribution of these two aspects on the loads measured by a force platform. The "saute" is a vertical leap with both feet from the first position and is considered a basic movement performed in an Allegro tempo.

METHODS: Six female ballet dancers (mean age $17 \pm 2,1$ years-old, mean mass $52 \pm 8,4$ kg, mean height $158,5 \pm 2,2$ cm) with at least six years of training (mean experience $8 \pm 2,8$ years) volunteered to this study. All dancers practice at least eight hours per week with slippers and pointe shoes and had no musculoskeletal injuries at the time of this experiment. All participants signed an informed consent form before testing. While positioned on the force platform, the dancer performed two trials of eight consecutive sautés from the first ballet position.

The time signatures 2/4 and 6/8 are binary tempos and the time unit used in this study was the quarter note. Consequently, in the condition 6/8, the movements were performed in the eighth note. This reveals the speed aspect of the dancer performances during this study.

Each dancer performed the following experimental design (Table 1):

Table 1 Experimental design.

Footwear: slippers		Footwear: pointe shoes	
	Time signatures		Time signatures
16 sautes 1 st position	2/4	16 sautes 1 st position	2/4
16 sautes 1 st position	6/8	16 sautes 1 st position	6/8

Only the vertical components of the resultant ground reaction forces were studied, because it better reflect the external loads applied to the body during landing from a jump. Ground reaction forces (GRF) were measured by a piezoelectrical force platform (Kistler Instruments), sampled at 1000Hz, low pass filtered with a cut off frequency of 200 Hz. Each sauté were divided into three phases: initial position (demi-plié or knees flexion), jump and landing (demi plié or knees flexion). For each sauté, the selected variables for descriptive purposes were: peak vertical force during landing (F_y), stance time (ST), vertical force rate of increase (R_{fy}). The time signature was determined by edited extracts from classical pieces, specially prepared for ballet classes, which were played on a CD-player. The data were tested for normality with a Shapiro Wilks test, and differences among the experimental conditions were tested with an analysis of variance one-way and a post-hoc Scheffe test.

RESULTS: In accordance with typical curves of each condition (Figures 1 and 2), the 6/8 time signature produces two vertical peaks and the 2/4 time signature produces only one peak of vertical force. Thus, the results suggest a greater influence of the musical beat in the accomplishment of the movement regarding the GRF loads. The footwear did not produce significant differences in the typical profile of the resultant curves.

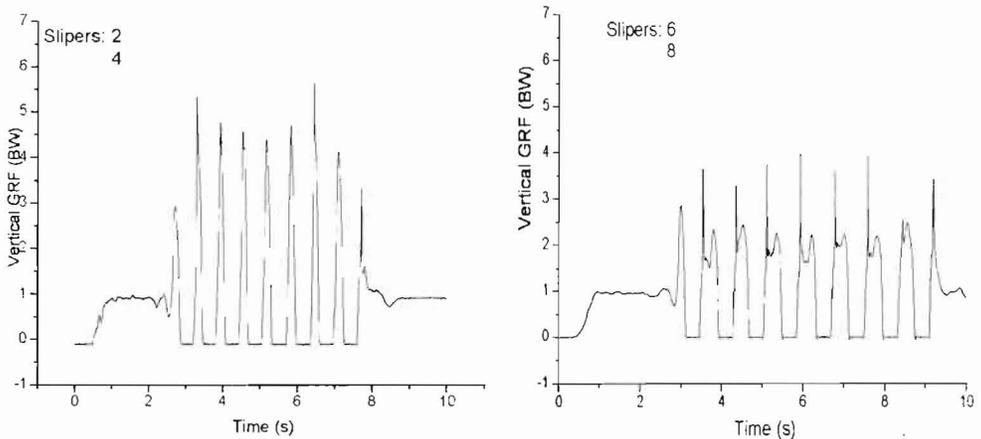


Figure 1: GRFy curves for saute using slipper in 2/4 and 6/8 time signatures. One trial and only one subject are represented.

Table 2 Descriptive values for the vertical forces during the saute with slippers (n = number of analysed sautes; BW = body weight).

	F_{y1} (BW) (mean \pm sd)	F_{y2} (BW) (mean \pm sd)	ST (s) (mean \pm sd)	R_{fy} (mean \pm sd)
Slipper shoes 2:4(n = 92)	3,60 \pm 0,70	----	0,35 \pm 0,09	33,11 \pm 9,57
Slipper shoes 6:8(n = 91)	2,80 \pm 0,82	1,83 \pm 0,34	0,63 \pm 0,09	26,98 \pm 9,78

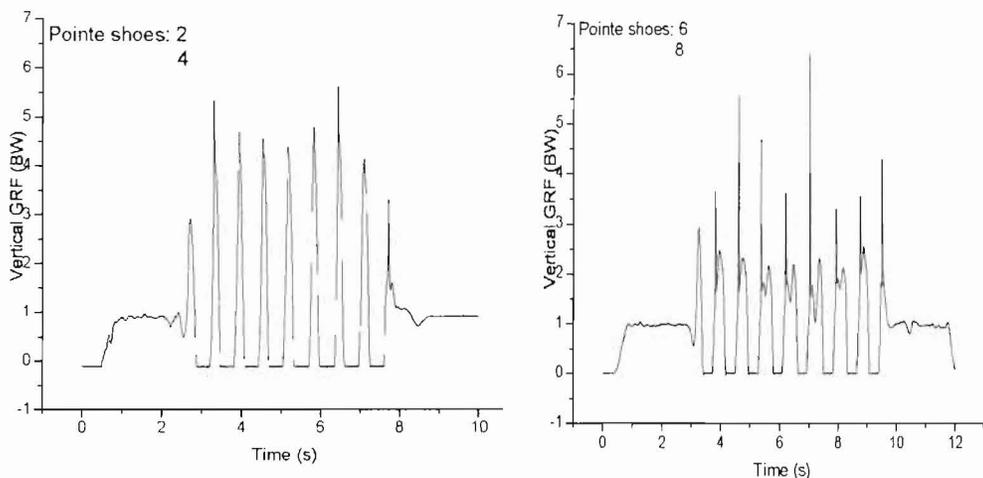


Figure 2: GRFy curves for saute using pointe shoes in 2/4 and 6/8 time signatures. One trial and only one subject are represented.

Table 3 Descriptive values for the vertical forces during the saute with pointe shoes (n = number of analyzed sautes; BW = body weight).

	Fy1 (BW) (mean \pm sd)	Fy2 (BW) (mean \pm sd)	ST (s) (mean \pm sd)	Rfy (mean \pm sd)
Pointe shoes 2/4(n = 94)	3,89 \pm 0,75	---	0,37 \pm 0,15	35,14 \pm 10,11
Pointe shoes 6/8(n = 90)	2,89 \pm 0,95	1,67 \pm 0,38	0,57 \pm 0,10	31,74 \pm 12,32

The values of Fy1 and Fy2 as well as the stance time and the rate of increase of the vertical force for the different conditions are presented in TABLE 2 and 3. For each condition, the total jump number was 96, however, some irregular jumps were eliminated. The stance time is the total duration from landing of the previous jump and preparation phase for the next jump. The vertical force rate of increase is an index which represents the ratio between the maximum vertical force magnitude and the time to reach this peak. Significant differences were found for the stance time observed for the different conditions ($p = 0,010$). The Sheffé post-hoc test pointed following differences (Table 4):

Table 4 Statistical differences for stance time in the four experimental conditions.

Post-hoc Sheffé test (ST of sautes)
2/4 slipper shoes < 6/8 slipper shoes ($p = 0,005$)
2/4 slipper shoes < 6/8 pointe shoes ($p = 0,034$)
2/4 pointe shoes < 6/8 slipper shoes ($p = 0,010$)

With respect to the vertical force rate of increase no differences were found for footwear and time signature conditions.

DISCUSSION: The ballet classes contain a great number of jump sequences. The saute represents one of the simplest jumps, generally used as a warm up exercise for the sequences of small chained jumps (named Batterie), or great jumps (named Grand Allegro). The saute landing phase is performed on both feet. The analyzed data have shown a significant difference for the stance time for the different experimental conditions. Thus, in the 2/4 condition the

stance times were lower (0,35s for sleeper shoes and 0,37s for pointe shoes, in average) than in the 6/8 conditions (0,63s for sleeper shoes and 0,57s for pointe shoes, in average). It is important to point out that the values obtained for the stance time were below or near to 50 ms, time needed for the muscular pre-activation response KANDEL (2000). This response is a strategy used by the locomotor apparatus to attenuate the impact produced during landing movements. Therefore, within this time interval (from 0 to 50 ms), the forces are absorbed by the locomotor apparatus in a passive way. The same author affirms that the true long latency reflex will only occur after 100 ms, time enough to elicit muscular eferent answers.

In the different conditions studied the stance time for saute varied between 20 to 70 ms (Tables 2 and 3). One has to remember that this time duration corresponds to the known passive phase. Despite the low stance times observed, the great number of jumps repeated with time and training in classic dancing may collaborate for good muscular conditions and thus a better ability to overload absorption by dancers. With relation to the footwear type, it was observed that the resultant vertical forces measured were not statistically different between slipper and pointe shoes conditions. In this way, the results pointed out that the musical beat may be a factor of greater influence on the vertical GRF, determining the different curves observed in this study.

CONCLUSIONS: Some questions that have motivated this study could be answered, revealing some peculiarities, mainly with respect to the influence of music beat and the myth of the pointe shoes danger. In accordance to these results pointe shoes do not produce greater overloads in relation to slipper shoes when measured the GRF. The time signature 6/8 produced greater stance times when compared to 2/4 time signature. In accordance to the observed results, music beat influences the mechanical aspects evaluated in this study more than the footwear type.

The statistic analysis did not show any relation or a more favorable combination of variables (better shoe or better time signature). There is a clear tendency to the fact that the faster the music beat, the greater the attention should be payed to the landing technique, mainly that of foot positioning on the ground, independently of the ballet shoe used.

Considering this, a number of questions still could be raised for future studies: comparisons between different qualities of jumps (petit allegro and grand allegro), comparisons between same types of ballet shoes from different manufactures, comparisons between professional and not professional dancers, among others. The research in dance can be developed with the aid of biomechanical methods for the benefit of the one of the most beautiful of the arts.

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