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Single leg balancing in ballet: Effects of shoe conditions and poses

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ABSTRACT

The purpose of this study was to describe the effects of lower limb positioning and shoe conditions on stability levels of selected single leg ballet poses performed in *demi-pointe* position. Fourteen female non-professional ballet dancers (mean age of 18.4 ± 2.8 years and mean body mass index of 21.5 ± 2.8 kg/m^2) who had practiced ballet for at least seven years, without any musculoskeletal impairment volunteered to participate in this study. A capacitive pressure platform allowed for the assessment of center of pressure variables related to the execution of three single leg ballet poses in *demi pointé* position: *attitude devant*, *attitude derriére*, and *attitude a la second*. Peak pressures, contact areas, COP oscillation areas, anterior–posterior and medio-lateral COP oscillations and velocities were compared between two shoe conditions (barefoot versus slippers) and among the different poses. Barefoot performances produced more stable poses with significantly higher plantar contact areas, smaller COP oscillation areas and smaller anterior–posterior COP oscillations. COP oscillation areas, anterior–posterior COP oscillations and medio-lateral COP velocities indicated that *attitude a la second* is the least challenging and *attitude derriére* the most challenging pose.

1. Introduction

Ballet dancers are known to engage in specific equilibrium exercises. Their expert levels of postural stability are responsible for some impressive movements in choreography when a dancer performs a balanced pose and holds the position for seconds. Many studies have attempted to reveal the superior equilibrium abilities of ballet dancers as compared to non-dancers during the performance of different postural tasks [1–4] and also in more specific ballet positions in relation to age and the presence of ankle injuries [5,6].

During the completion of single leg ballet poses the gesturing leg performs the step and the supporting leg is responsible for weight bearing. In most poses, the supporting foot is in a *demi-pointe* position (90° extension of the metatarsophalangeal joint) in which the narrower portion of the posterior talus lies within the ankle mortise, resulting in a less stable joint configuration [6]. Thus in the *demi-pointe* position the equilibrium demand is enhanced as compared to poses performed with the entire foot on the ground, which is a situation that does not allow to discern the specific equilibrium demands often imposed to ballet dancers [6].

The proprioceptive function of ballet dancers may be altered by injuries [6] and footwear has the potential effect of restricting foot motion, leading to loss of stability and injuries [7]. Thus we can suppose that the use of ballet shoes may also play a role in postural stability, by affecting foot motion to control body oscillations.

Dancers are known to exhibit enhanced haptic-proprioceptive awareness of limb position [8] with a more developed position sense of lower extremities [6] that enables them to anticipate slight balance adjustments [9]. In this context we can suppose that stability of dancers may be challenged by differences in gesturing leg positions.

It is thus the purpose of this study to describe the effects of lower limb positioning and shoe conditions on stability levels of selected single leg ballet poses performed in *demi-pointe* position.

We hypothesized that barefoot performances would result in increased contact areas, lower plantar pressures and more stable postures, when they are compared to performances with ballet slippers. Furthermore, we did not expect the different gesturing limb positioning to influence plantar pressure variables because they do not produce changes in the foot position; however, we expect the poses to affect center of pressure (COP) variables differently because the pattern of force transfer through the foot to the ground depends on the positioning of body segments and the conditions of the supporting foot.

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2. Materials and methods

Fourteen experienced, non-professional, female ballet dancers aged between 15 and 25 years (mean age 18.4 ± 2.8 years, body height 162.8 ± 5.4 cm, body weight 57.8 ± 8.1 kg and body mass index 21.5 ± 2.8 kg/m^2) without any musculoskeletal pain and impairment and that had practiced ballet for at least seven years volunteered to participate in this study. All dancers answered a questionnaire about their ballet training experience and previous foot injuries. Subjects were informed about the purpose and procedures of the study and were asked to provide their informed consent before the experimental procedures began. The research protocol was approved by the Ethics Committee of the Federal University of São Carlos (process number: 4060/2010).

In two experimental conditions, with slippers and barefoot, the ballet dancers performed the following balance poses standing on one foot: *attitude devant*, *attitude derriére* (Fig. 1), and *attitude a la second*. The dancers were instructed to hold the positions for 4 s. These positions require the body to be supported by the toes and metatarsal heads of the feet in a plantar flexed position of the ankle joint and must be mastered by experienced classical dancers.

Plantar pressure variables and the center of pressure (COP) applied to the supporting foot were quantified with a capacitive pressure measurement platform (EMED ST 4, Novel, Germany) at 50 Hz sampling rate and a spatial resolution of four sensors per square centimeter. Peak pressures (in kPa), contact areas (in cm^2), COP oscillation areas (in cm^2), anterior–posterior and medio-lateral COP oscillations (in cm) and velocities (in cm/s) were compared between experimental conditions (barefoot versus slippers) and the three different ballet poses. Center of pressure is defined as the point of application of the resultant vertical reaction forces under the feet, and it is the outcome of inertial forces and the restoring equilibrium forces of the postural control system [10]. Velocity measurements of the COP have been used to describe postural behavior [11] and have been shown to be reliable and valid [12].

A custom-written Matlab code (The MathWorks Inc., USA) was used to compute COP variables [13] in order to determine the postural demands in different conditions. After removing the mean by a de-trending operation the root-mean-squares of the anterior–posterior and medio-lateral COP trajectories were calculated to quantify the COP oscillations. COP velocities were calculated by differentiation of COP displacements over time in the anterior–posterior and medio-lateral directions. The COP oscillation area in the plane of the platform was fitted to an ellipse that contained 95% of that oscillation, with the axes (minor and major) calculated by principal component analysis [13].

Fig. 1. *Attitude derriére* performed barefoot in demi-pointe position. With permission.

Each dancer performed three valid trials of each ballet pose in a randomized order. The arm positions were standardized as follows: in *attitude devant* the gesturing leg is in front of the body, the contralateral arm is positioned in front of the body with a shoulder flexion of 90°, and the ipsilateral shoulder is abducted to the shoulder height; in *attitude derriére* the gesturing leg is behind the body, the ipsilateral arm is in front of the body with a shoulder flexion of 90°, and the contralateral shoulder is abducted to the shoulder level; in *attitude a la second* the gesturing leg is at one side and both arms are positioned with shoulder abduction to a height slightly lower than the shoulder level. Each subject adopted the required pose on the pressure platform, and then sampling was initiated.

The average of three successful trials was used for further analyses. For statistical analysis, the Statistical Package for Social Sciences (SPSS for Windows 10.01, IBM, USA) was used. The variables were first tested for normality with Kolmogorov–Smirnov and Shapiro–Wilk tests. A repeated measures Analysis of Variance with Bonferroni adjustments for multiple comparisons of the main effects was applied to the normally distributed data. Sphericity assumptions were violated for foot conditions, therefore degrees of freedom were corrected using Geisser/Greenhouse technique. Simple contrasts were tested for shoe conditions and poses, for which barefoot and *attitude derriére* were used as the control categories. Non-parametric Friedman tests were performed with the peak pressure variable. The significance level was determined for $p < 0.05$.

3. Results

According to the results of the questionnaire, the ballet dancers who participated in this study can be characterized as well-experienced, non-professional practitioners with more than seven hours of practice per week who were all affected by previous foot disorders that did not impose limitations for the measurements.

3.1. Shoe conditions effects

Barefoot performances produced significantly larger contact areas than performances with slippers: $F(1,13) = 22.45$, $p < 0.01$ (Table 1). Peak pressures were not significantly different when the poses were performed barefoot and with slippers (Table 1). Main effects for shoe conditions were also found for COP oscillation areas and anterior–posterior COP oscillations: $F(1,13) = 5.962$, $p = 0.03$ and $F(1,13) = 11.326$, $p = 0.005$, respectively. Significantly smaller COP oscillation areas and anterior–posterior COP oscillations were produced during the barefoot performances for *attitude devant* and *a la second* but not for *attitude derriére* (Table 2). There were no main effects of shoe conditions for medio-lateral COP oscillations, anterior–posterior and medio-lateral COP velocities (Table 2).

3.2. Ballet poses effects

Contact areas and peak pressures were not affected by the three different ballet poses (Table 1). Main effects for poses were found for areas of COP oscillations: $F(2,26) = 5.008$, $p = 0.01$. Among the ballet poses, *attitude derriére* produced significantly larger areas of COP oscillations than *attitude devant* and *a la second* only when performed barefoot (Table 2). When slippers were used, areas of COP oscillations were not significantly different. Main effects of poses were also found for anterior–posterior COP oscillations and medio-lateral COP velocities: $F(2,26) = 10.289$, $p = 0.001$ and $F(2,26) = 7.925$, $p = 0.002$, respectively. Among the three poses, *attitude derriére* produced the largest anterior–posterior COP oscillations when performed barefoot, but when performed with slippers the three poses were not significantly different. There were no significant differences among any ballet poses for medio-lateral COP oscillations and anterior–posterior COP velocities (Table 2). The highest medio-lateral COP velocity was found for *attitude derriere*. *Attitude a la second* produced the lowest medio-lateral COP velocities (Table 2).