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Research Article

Effect of *en dehors* on dynamic postural control, impact force and plantar force distribution in dancers with ankle instability during jump landing

JULIA M. PORTUGAL[1] | ISABELLA M. RODRIGUES[1] | KARINE J. SARRO[1]

[1] Universidade Estadual de Campinas, Faculdade de Educação Física, Campinas, SP, Brazil

Correspondence to: Julia Martins Portugal
Universidade Estadual de Campinas, Faculdade de Educação Física
Av. Érico Veríssimo, 701 - Cidade Universitária "Zeferino Vaz". CEP: 13.083-851 - Barão Geraldo - Campinas - SP – Brazil
Phone: +55 19 989410589
email: julia.mportugal98@gmail.com
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HIGHLIGHTS

- Dancers present worse dynamic postural control in the jump with en dehors.
- Dancers present higher impact force in the jump with en dehors.
- Dynamic postural control and impact force were independent of CAI.
- Dancers with CAI present higher plantar force on the lateral hindfoot.

ABBREVIATIONS

CAI	Chronic ankle instability
CAIT	Cumberland Ankle Instability Tool
CG	Control group
COPap	Anteroposterior displacement of the center of pressure
COPml	Mediolateral displacement of the center of pressure
Fz	Peak of the vertical ground reaction force
IG	Instability group

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BACKGROUND: A possible aggravating factor to the loss of balance in jumps in classical ballet is the position of the lower limbs in external rotation (*en dehors*), which could be even worse in ballerinas with chronic ankle instability (CAI).
AIM: To investigate the effect of the *en dehors* position during jump landings in dancers with chronic ankle instability (CAI), assessing postural control, impact force and plantar force distribution.
METHODS: Twelve dancers without and 10 with CAI were analyzed during jump landings with and without *en dehors*. The anteroposterior and mediolateral displacement of the center of pressure (COPap and COPml) and the peak of the vertical ground reaction force (Fz) were evaluated by a force platform. The peak plantar force was estimated in 8-foot regions by a pressure distribution system. The data were compared by 2-way ANOVA of mixed models considering the factors group with two levels (control and CAI) and type of jump with two levels (without or with *en dehors*), considering $p < 0.05$.
RESULTS: COPml (3.70 ± 0.82 cm and 3.39 ± 0.50 cm in the control and instability group) and Fz (2.25 ± 0.36 N/bw and 2.40 ± 0.28 N/bw in the control and instability group) were higher in the sauté jump. The force in the lateral hindfoot was greater in the instability group in both jumps (0.30 ± 0.20 N/bw without *en dehors*; 0.37± 0.14 N/bw with *en dehors*).
INTERPRETATION: The ballerinas presented worse dynamic postural control and higher impact force in the jump with en dehors. Ballerinas with CAI discharge more force on the lateral hindfoot when landing, a pattern consistent with a higher risk of ankle sprain, regardless of the *en dehors*.

KEYWORDS: Classical ballet | Chronic ankle instability | Dynamic balance | Center of pressure | Ground reaction force

INTRODUCTION

Dance requires a lot of work from the lower limbs, especially in some modalities, such as classical ballet. Among the possible lower limb injuries in ballet, ankle sprains and strains are some of the most common types [1]. Considering the general adult population, forty percent of patients with ankle sprains are known to develop chronic ankle instability (CAI) [2], a condition that raises the hypotheses that it could lead to a worsening of postural stability. Specifically, in ballet, dancers with a previous ankle sprain have worse static postural stability in the first and fifth ballet foot positions with their feet on the ground and on the toes (with the pointe shoe) when compared to dancers without injury [3].

Whereas classical ballet involves a number of difficult maneuvers such as jumps, landings, twists, and lifts with dance partners, failure to perform these movements correctly can lead to acute foot and ankle injuries [4]. Jumps in classical ballet are of great importance, however when improperly performed, result in joint injury [5], by the excess of force and consequent impact, or by the loss of balance during landing [6]. A possible aggravating factor to the loss of balance during landings in classical ballet is the position of the lower limbs, characterized by a maximum of external rotation (*en dehors*). Studies have shown that *en dehors* relies on a complex interaction between all joints of the lower limbs and not just the hip as expected [7], including the knee joint, a tibia twist, toes positioned outward along with a dorsiflexion of the ankle [8]. Therefore, the landing of jumps in ballet depends on a set of variables, such as the permanence of the *en*

dehors during the movement [9], the impact of the landing on the lower limbs, a correct positioning of the body and a great postural control at the end of the movement.

Studies conducted on the classical technique constituted by the *en dehors* demonstrated a high rate of knee injuries in the landing of jumps, however, to the best of our knowledge, an investigation of the effect of the *en dehors* on the landing of jumps in dancers with chronic ankle instability (CAI) and its possible changes has not been done yet. A study showed that dance experience can mitigate the effects of ankle instability in conventional tests [10], so it is important to better understand if dancers with CAI are more prone to adaptations related to a higher risk of injury while dancing. Therefore, the aim of this study was to investigate the effect of *en dehors* on dynamic postural control and plantar force distribution during jump landings in dancers with CAI.

METHODS

Participants

We analyzed 22 amateur female dancers (intermediate or advanced levels, with a frequency of at least 4 classes per week, 2 classes or more of classical ballet), being 10 with chronic ankle instability (IG - Instability Group: 21.60 ± 4.24 years ;55.99 ± 6.26 kg; 1.62 ± 0.026 m; 14 ± 0.02 years of ballet practice), and 12 without ankle instability (CG - Control Group: 21.50 ± 2.14 years; 56.87 ± 15.20 kg; 1.62 ± 0.06 m; 13.25 ± 5.26 years of dance practice). All the participants answered the Cumberland Ankle Instability Tool (CAIT) questionnaire [11], and an anamnesis questionnaire containing anthropometric information and about their dance experience and injury history. To be included in the IG, they were required to meet the criteria established by the International Ankle Consortium. These criteria included having a history of at least one significant ankle sprain, as well as evidence of a previously injured ankle joint. Additionally, participants had to report symptoms such as weakness, recurrent sprains, and/or a feeling of instability in the affected ankle, and obtain a score lower than 24 on the CAIT. To be included in the CG, the participants had to obtain a score higher than 24 on the CAIT, and not have significant ankle sprains or report symptoms similar to those in the IG. Participants with a history of surgery or fractures in the lower limbs or who had suffered lower limb injury in the 3 months prior to data collection were not included. To identify the dominant lower limb, all participants answered the Waterloo Footedness Questionnaire-Revised [12].

The project was approved by the Human Research Ethics Committee of the Faculty of Medical Sciences of the University of Campinas (51636321.7.0000.5404). All participants signed an informed consent form before participating in the study.

Figure 1. Photo of the equipment positioning in one of the participants.

Experimental procedure

After a short warm-up, the participants placed the Pedar-x insoles inside their shoes and the equipment was placed on their bodies, so as not to interfere with the execution of the jump (figure 1). After that, the jumping protocol was explained, which could be

practiced 3 times before the acquisition of the data. The test should not be performed more than 3 times, so as not to generate muscle fatigue or an adaptation of the body to the jump. The participants were instructed to perform three single-leg jumps without *en dehors* (Single-Leg Countermovement Jump), and three single-leg jumps with *en dehors* (Simple Sauté), in random order, with the dominant side (CG) or side of greater ankle instability (IG). There was a short rest between the Single-Leg Countermovement Jump and the Simple Sauté (2 to 3 minutes), and the participants were also instructed to jump as high as they could. The jumps were performed on a force platform with the pedar-x equipment on their bodies simultaneously. Dynamic postural control (characterized by the displacement of the center of pressure in the anteroposterior and mediolateral directions - COPap and COPml) and the peak of the vertical component of the ground reaction force (Fz) were evaluated by a force platform (Kistler 9286BA, 500 Hz), while the peak of plantar force was estimated from the pressure distribution measured by the Pedar-x system (Novel, Germany, 100 Hz). A mask model that divides the foot anatomically into 8 regions was used: hallux, toes, region from first to third metatarsals, region from the fourth to the fifth metatarsals, lateral and medial region of the midfoot, lateral and medial region of the hindfoot.

Data analysis

The software IBM SPSS Statistics 25 was used for the statistical analysis. The Kolmogorov-Smirnov test was performed to verify the normal distribution of the variables and Levene's test for equality of variances. The variables COPap(cm) and COPml(cm), Fz (N/BW) and Plantar pressure force (N/BW) in different foot regions for the control (CG) and instability groups (IG) during Single Leg Countermovement Jump and Sauté were tested. The data were compared by 2-way ANOVA of mixed models considering the factors group with two levels (control and CAI) and type of jump with two levels (without or with *en dehors*), considering $p < 0.05$.

RESULTS

The vertical ground reaction force and the plantar force in the different regions of the foot can be seen in figures 2 and 3 respectively. The following variables were higher in the sauté jump, regardless of the group: COPml ($p = 0.00$), Fz ($p = 0.002$), (figure 2).

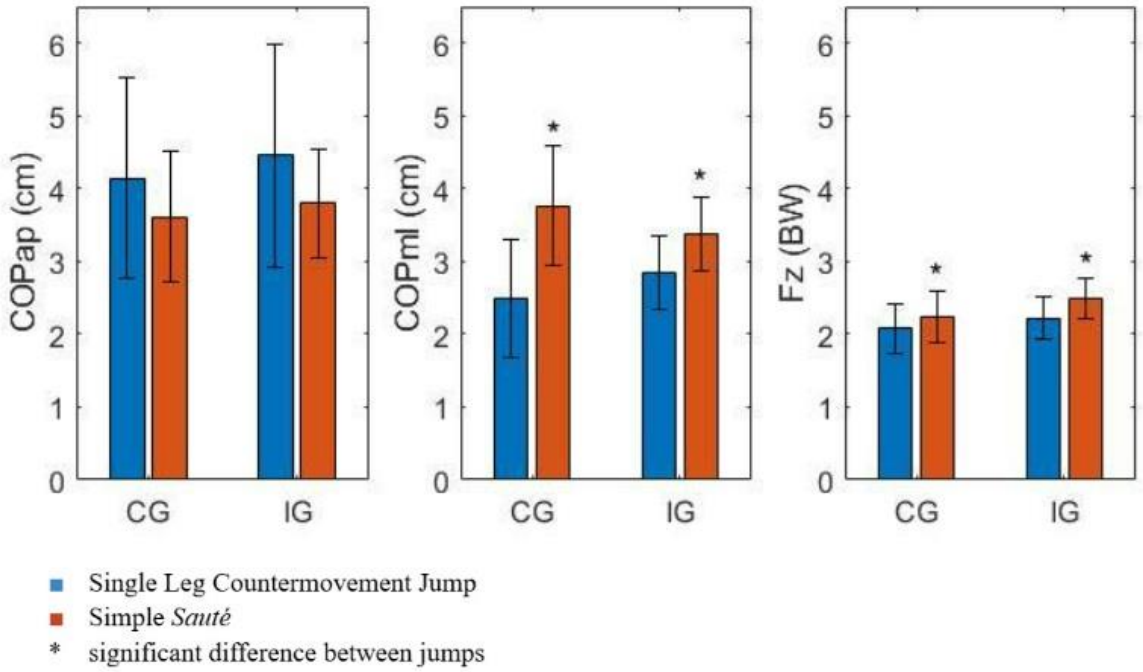

Figure 2. COPap(cm) and COPml(cm), and Fz (Newton normalized by body weight) for the control (CG) and instability groups (IG) during Single Leg Countermovement Jump (blue) and Sauté (red).

The following variables were higher in the sauté jump, regardless of the group: force in the medial hindfoot ($p = 0.04$) and force in the medial forefoot ($p = 0.01$). On the other hand, the force in the lateral hindfoot region was significantly higher in the group with CAI in both jumps ($p = 0.01$), (figure 3).

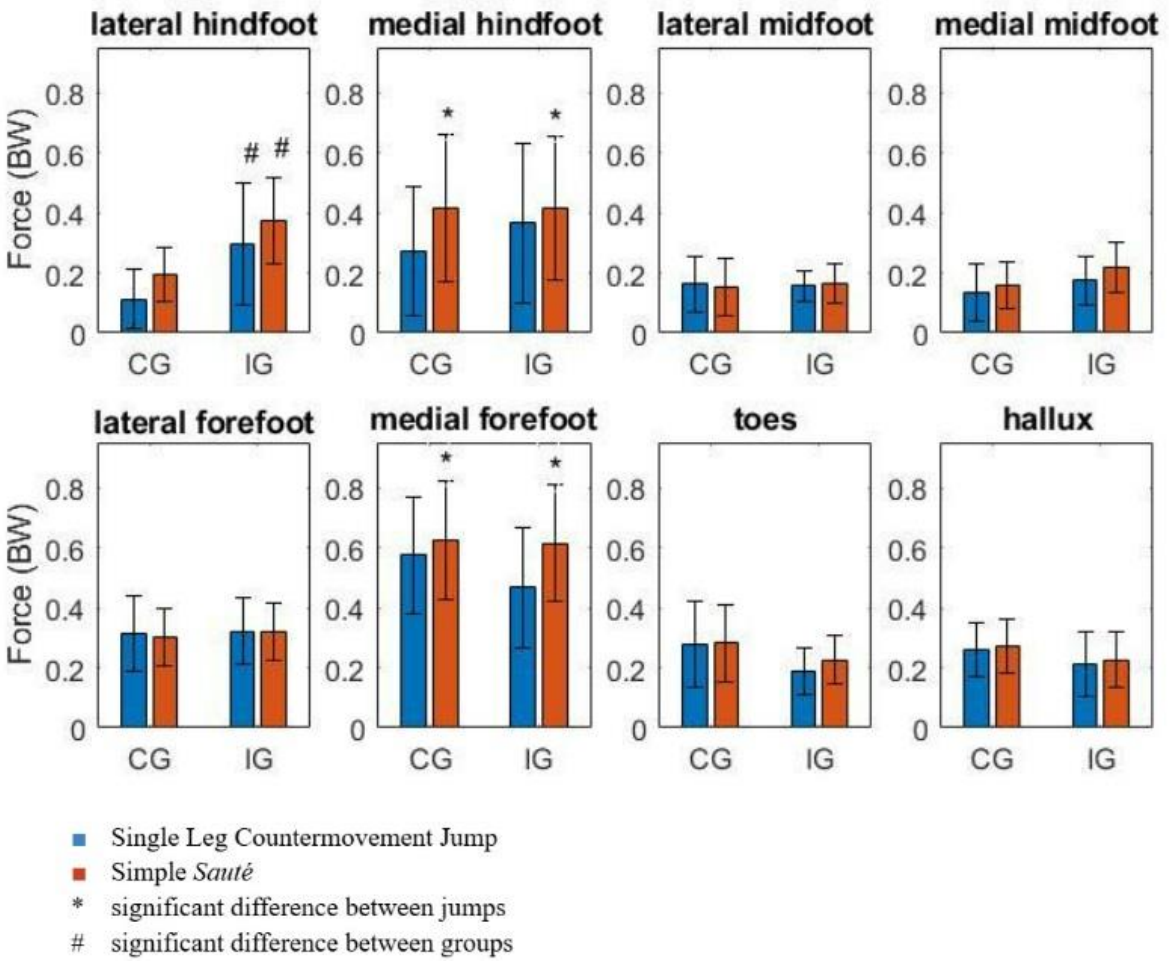

Figure 3. Plantar pressure force (Newton normalized by body weight) in different foot regions for the control (CG) and instability groups (IG) during Single Leg Countermovement Jump (blue) and Sauté (red).

DISCUSSION

The objective of this study was to investigate the effect of the *en dehors* position during jump landings in dancers with chronic ankle instability (CAI), assessing postural control, impact force and plantar force distribution. Dancers presented worst dynamic postural control and higher impact force in the jump with *en dehors*, independently of CAI. However, dancers with CAI demonstrated increased plantar force on the lateral hindfoot in both jumps.

The differences in dynamic postural control and in the peak ground reaction force found between the jumps showed worse results in the specific ballet jump, regardless of the presence of ankle instability. When compared to the single leg, the sauté differs in performing the entire jump, since with the external rotation of the lower limbs (*en dehors*) even the base of support is modified [9]. Although there is evidence that patients with ankle instability have a higher peak of vertical ground reaction force [13], we did not find the same results in dancers with CAI. On the other hand, the highest peak of vertical force was identified in the jump with *en dehors*, which may indicate a stiffer landing and, consequently, a greater impact force in the jump with external rotation, compared to the jump without rotation [14].

It is known that ankle sprains usually occur during jumping and landing activities [15,16,17,18,19] in inversion position of the foot [20,15], and can lead to chronic ankle instability [21]. The peak of plantar force on the lateral hindfoot at landing was the only variable that presented a difference between the groups, being higher in the dancers with ankle instability in both jumps. The greater force found in the lateral hindfoot of the dancers in the group with instability is consistent with the greater inversion found in people with ankle instability and during sprains [15]. Therefore, the greater force on the lateral hindfoot during landing found in dancers with instability reaffirms the risks of sprain in the inversion position of the foot. This points out that force in different regions of the foot, from the use of a plantar pressure distribution system, can be used to identify ballerinas at risk, monitor the progress of rehabilitation and adjust treatment plans as needed. Those results suggest the need for injury prevention programs that address dynamic postural control specific to dancers, as well as adaptation

of the technique to attenuate the impact force.

The study shows that the dynamic motor control of dancers is more compromised when the *en dehors* position is used. In terms of motor control, this suggests that the presence of external rotation of the lower limbs during jumping and landing may increase the demand on the nervous system to maintain balance. The greater difficulty in maintaining postural control with *en dehors* may be related to a greater complexity in the intermuscular coordination required to compensate for the loss of stability, which could be investigated in future studies. The increase in the anteroposterior (COPap) and mediolateral (COPml) displacement of the center of pressure indicates that they need more refined motor control to deal with instability. The greater oscillation of the center of pressure can be interpreted as an attempt by the nervous system to react to the risk of falling, activating different muscle groups in a compensatory manner to stabilize the body.

The study also suggests that ankle instability interferes with dancers' ability to coordinate the movements required for a stable and efficient landing. Motor control during landing is a complex process that involves the integration of multiple sensory and motor systems. In the case of dancers with CAI, the impairment in sensory perception and reduced ankle stability require more conscious and less automatic motor control, which can increase the risk of coordination failures and, consequently, injury. Overall, the results of this study provide a solid foundation for more effective clinical interventions and injury prevention and training programs.

There are some limitations to the study. The possible influence of the number of trials due to variability was not tested. Although three trials were sufficient to identify significant and coherent results, further research is needed to explore this aspect.

CONCLUSION

The dancers presented worse dynamic postural control and greater impact force in the jump with *en dehors*, regardless of the presence of ankle instability, suggesting that the performance of the jump with *en dehors* puts these dancers at greater risk of injury. However, dancers with CAI demonstrated plantar force pattern coherent with a higher risk of ankle sprain regardless of *en dehors*, reinforcing the need for early identification of CAI, as well as its treatment and prevention in dancers.

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