Demands at the Knee Joint During Jumps in Classically Trained Ballet Dancers

Thiago Lemes, Guilherme De Villa, Adriano Rodrigues, Johelma Galvão, Rina Magnani, Rodrigo Gomide, Michelle Millan, Eduardo Mesquita, Luís Carlos Borges and Marcus Vieira

November 16, 2020

Demands at the Knee Joint During Jumps in Classically Trained Ballet Dancers

T. S. Lemes[1], G. A. G. De Villa[1], A. P. Rodrigues[1], J. M. A. Galvão[1], R. M. Magnani[1,2], R. S. Gomide[1], M. B. Millan[1], E. M. Mesquita[1], L. C. C. Borges[1] and M. F. Vieira[1]

[1] Bioengineering and Biomechanics Laboratory, Federal University of Goiás, Goiânia, Brazil
[2]State University of Goiás, Goiânia, Brazil

Abstract— **The aim of this study was to analyze the differences in ground reaction strength and knee mechanics joint in four jumps usually trained in ballet: Changement, Echappé Sauté 1 (fifth position for second position), Echappé Sauté 2 (second position for fifth position) and Sauté. Fifteen professional dancers participated in this study, exceeding a weekly 15 hours of classes. The participants performed three trials of each jump in a randomized order on a force platform. The Sauté jump produced the greatest peak knee moment in both propulsion (<0.001) and landing phases(<0.001), but the lowest rate of force development in propulsion phase (0.023). These results indicate that Sauté is performed with a deeper plié in both propulsion and landing phases, with smaller ground reaction force peak and knee peak force. This pattern of jumping may be less harmful and should be adopted in the other jumps by classical dancers who perform such exercises daily several times.**

Keywords— **Demand, jumps, knee**

I. Introduction

The specificities of classical ballet require a lot of dexterity and training to perform the only form of dance that encompasses a high level of athletics and unique visual aesthetics [1]. The practice of dance, including classical ballet at high levels of preparation, can be considered a sport, due to the amount of intense rehearsals and classes performed by its practitioners [2]. Around 73% of the severe injuries were traumatically caused when performing jumps and lifts [3]. One of the aspects that most demand ballet practice is the jumping movements [4] which require a high mechanical demand for rapid muscular effort in the lower extremity and are associated with joint injuries. There are an alarming number of injuries caused by the frequent practice of ballet, and some studies [5,6] report that injuries to the feet, ankles, knees and spine occur constantly, so that these segments are susceptible of chronic and acute illnesses. The most frequently knee injuries in dancers are related to patellar alignment, inflamed plica, or torn meniscus or cruciate ligaments [7].

The ground reaction force (GRF) is a variable of interest due to its potential correlation with high injury rates. Greater ground reaction force can have harmful effects on the body and can result from an inadequate ground surface, poor technique, or footwear used [8].

Professional classical dancers perform more than 200 jumping and/or landing actions in daily training sessions. Vertical jumps have been used in studies[9–11] as tests to evaluate the performance and other characteristics of the lower limbs. Some of the daily jumps of classical ballet have characteristics like those of vertical jumps, as they are jumps that do not have anterior-posterior displacement and have phases of propulsion, flight, and landing. Thus, variables and calculations similar to those of studies involving vertical jumps can be used to evaluate these ballet jumps [12].

Therefore, the aim of this study was to analyze the differences in knee demand in four jumps usually trained in ballet: Changement, Echappé Sauté 1 (fifth position for second position), Echappé Sauté 2 (second position for fifth position) and Sauté, to verify which jump has the greatest potential for injuries. We hypothesize that landing phase produces results more deleterious than propulsion phase, and the jumps performed in fifth position would be of greater risk.

II. Material and methods

A. Subjects

Fifteen individuals (6 males and 9 females; age: 21,4±3,1 years; body mass: 57,2±8,6 kg; height: 1,66±0,08 m) participated in the study with ballet experience of 10,6±5,9 years, and exceeding a weekly 15 hours of classes. All participants were tested in individual sessions. The subjects performed three trials of each jump in a randomized order on a force platform. The execution of all trials was validated by a dance specialist, who also applied a question form to learn about demographic characteristics and possible injuries.

B. Protocol

The volunteers were instructed to perform the jumps keeping their hands on their waist to exclude the contribution of the upper limbs. They were also instructed to perform the jumps as they do during classes.

A force platform (AMTI, model OR6-7) positioned on a flat and stable surface was used to collect GRF. Both kinetic and kinematic data were captured using full body plug-in-gait at sampling frequency of 100 Hz by the Vicon system, which includes 10 infrared cameras (Vicon Nexus, Oxford Metrics, Oxford, UK).

Individual kinetic variables were extracted: sagittal plane net maximum knee load (KFmax), maximum knee moment (KMmax), and maximum knee power (KPmax), rising time (RT), peak of vertical GRF and mean rate of force development (RFD) [13] for the propulsion and landing phases of classical ballet jumps. Next, an average of the three trials was calculated.

The propulsion phase was calculated from the deepest squat, called plié in classical ballet, until the loss of contact with the force platform. The landing phase was calculated from the instant of contact with the force platform to the deepest plié.

C. Statistical Analysis

For each variable, as all data had a normal distribution the one-way ANOVA test was used to determine differences between jumps. A post-hoc test with Bonferroni correction was conducted when ANOVA was significant. All statistical analysis was performed using SPSS software (SPSS Inc. Chicago, IL, USA), with a significance level set at $\alpha < 0.05$.

III. Results

Tables 1 and 2 below show the results for the four jumps, in the propulsion and landing phases, respectively.

Table 1 Variables analyzed for the Changement, Echappé 1, Echappé 2 and Sauté in propulsion phase

Jump	Changement	Echappé 1	Echappé 2	Sauté	p
KFmax (N/kg)	3.1 ± 0.8	3.1 ± 0.2	2.1 ± 0.9	2.6 ± 0.9	0.152
KMmax (N.mm/kg)	672,2 ± 216.2	534.1 ± 168.6	332.8 ± 179.5	1233.5 ± 267.4	**<0.001**
KPmax (W/kg)	45.2 ± 15.0	25.1 ± 7.0	13.5 ± 7.3	22.7 ± 10.2	0.351
Rising Time (s)	0.24 ± 0.04	0.22 ± 0.04	0.15 ± 0.04	0.36 ± 0.15	**0.010**
Peak GRF (N/kg)	28.2 ± 2.9	25.7 ± 1.2	23.6 ± 3.2	25.6 ± 3.23	0.568
Mean RFD (N/kg/s)	70.7 ± 24.8	69.1 ± 13.1	96.1 ± 22.9	48.4 ± 22.7	**0.023**

Table 2 Variables analyzed for the Changement Echappé Sauté 1. Echappé Sauté 2 and Sauté in landing phase

Jump	Changement	Echappé1	Echappé2	Sauté	p
KFmax (N/kg)	6.8 ± 4.3	6.3 ± 4.2	7.6 ± 5.2	6.0 ± 3.8	0.943
KMmax (N.mm/kg)	437.5 ± 212.9	448.1 ± 288.2	392.6 ± 275.2	1355.5 ± 234.1	**<0.001**
KPmax (W/kg)	10.8 ± 6.5	20.5 ± 10.5	18.2 ± 7.6	10.4 ± 4.0	0.306
Rising Time (s)	0.11 ± 0.03	0.11 ± 0.02	0.12 ± 0.02	0.10 ± 0.02	0.419
Peak GRF (N/kg)	33.8 ± 7.0	35.3 ± 7.7	29.8 ± 7.6	30.2 ± 10.1	0.666
Mean RFD (N/kg/s)	202.1 ± 127.1	207.0 ± 101.6	153.8 ± 78.1	200.4 ± 126.6	0.858

Overall, KFmax, peak GRF, and mean RFD were greater for landing phase than for propulsion phase, whereas KPmax and rising time were smaller for landing phase than for propulsion phase.

During the propulsion phase, significant differences were found for KMmax ($p < 0.001$), RT ($p = 0.010$) and RFD ($p = 0.023$). Sauté produced greater KMmax than the other jumps, greater RT than Echappé 2 (post-hoc $p = 0.007$), and Echappé 2 produced greater RFD than Sauté (post-hoc $p = 0.017$).

During the landing phase, significant differences were found only for KMmax ($p < 0.001$). Sauté produced greater KMmax than the other three jumps ($p = 0.001$, $p= 0.001$, and $p < 0.001$ for Changement, Echappé1, and Echappé2, respectively).

IV. Discussion

The aim of this study was to evaluate the differences in demand on the knee joint during the propulsion and landing phases of four common dance jumps Changement, Echappé Sauté 1 (fifth position for second position), Echappé Sauté 2 (second position for fifth position) and Sauté. The hypothesis was that landing phase produces greater demands on the knee joint than propulsion phase, and that the jumps performed in fifth position would be of greater risk. The results of this study support the first hypothesis, but not the second one.

The results confirm that landing phase is more demanding than propulsion phase. The shorter rising time is in line with greater RFmax and peak GRF values. These results are in accordance with Kulig at al. (2011) who found similar results for this same joint, although with a different jump, Saut de Chat [14].

A component that should be highlighted in the vertical attenuation of the reaction force of the ground is the stiffness of the legs, composed of compressibility of the tissue and angular stiffness of the individual joints. The greater the physical demand for activity, the greater the amount of stiffness that a leg presents [15]. The knee seems to be the main articulator, among those of the members lower legs, the stiffness of the legs, because the components of the lever arms of the femur and tibia put the knee in the best position to help mitigate the vertical ground reaction forces [16,17]. In this study, for some jumps, landing, which involves greater vertical GRF, was performed with lower Moment Forces than the takeoff phase, indicating less knee joint stiffness for this phase.

Sauté produced greater values of KMmax and RT, and smaller RFD in propulsion phase, and greater KMmax during landing phase. These results indicate that, overall, the plié executed by the participants prior and after Sauté is deeper than in the other jumps, which, in turn, produced smaller peak GRF and KFmax. This strategy of jumping may be less harmful and should be adopted in the other jumps to prevent knee injuries.

Studies show that knee injuries are the second most prevalent type of musculoskeletal injuries that affect dancers. This occurs due to the initial and final positions adopted in most movements, where there is an increase in the external rotation of the knee and hyperextension, generating ligament laxity and joint instability. In addition, an excessive repetition of the choreography or a specific movement after fatigue that affects the decrease in the integrity of the musculotendinous or the mechanism commonly responsible for various injuries [18–20].

One limitation of the present study is related to executing the jumps in isolation, and not in a set of jumps that are usually choreographed in ballet. Another possible limitation was that the jumps were tested with the participants barefoot to control a possible influence of footwear in the performance of the jump [21].

V. CONCLUSIONS

This study identified that, for the four analysed jumps, Sauté appears to be performed in a safer way, which should be adopted in the other jumps. Future studies may focus if such pattern of execution adopted in Sauté jump, with a deeper plié before and after the jump, can decrease the potential of injury of the other jumps.

ACKNOWLEDGMENT

The authors would like to thank the financial support of the National Council for Scientific and Technological Development (CNPq), the Coordination for the Improvement of Higher Education Personnel (CAPES), the Foundation for Research Support of State of Goiás (FAPEG). M. F. Vieira is a CNPq fellow, Brazil (306205 / 2017-3).

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

1. Shantz P G, Strand P (1984) Physiological characteristics of classical ballet. Med Sci Sport Exerc 16:472-6 DOI 10.1249/00005768-198410000-00009.
2. Guarino L (2015) Is dance a sport? A twenty-first-century debate. J Danc Educ 15:77–80. DOI 1529-0824
3. Arendt Y, Kerschbaumer F (2003) Verletzungen und Überlastungserscheinungen im professionellen Ballett. Z Orthop Ihre Grenzgeb 141:349–56 DOI 10.1055/s-2003-40088.
4. Arendt Y, Kerschbaumer F (2003) Verletzungen und Überlastungserscheinungen im professionellen Ballett. Z Orthop Ihre Grenzgeb 141:349–56 DOI 10.1055/s-2003-40088.
5. Kadel NJ (2006) Foot and Ankle Injuries in Dance. Phys Med Rehabil Clin N Am 17:813–26 DOI 10.1016/j.pmr.2006.06.006
6. Tuckman A S, Werner F W, Bayley J C (1991) Analysis of the Forefoot on Pointe in the Ballet Dancer. Foot Ankle 12:144–8 DOI 10.1177/107110079101200303
7. Teitz CC (2000) Hip and Knee Injuries in Dancers. J Danc Med Sci 4:23–9 DOI 10.2165/00007256-198806050-00005
8. McPherson AM, Schrader JW, Docherty CL (2019) Ground Reaction Forces in Ballet Differences Resulting from Footwear and Jump Conditions. J Danc Med Sci 23:34–9 10.12678/1089-313X.23.1.34
9. Peng H-T, Chen W et al (2015) Influences of Patellofemoral Pain and Fatigue in Female Dancers during Ballet Jump-Landing. Int J Sports Med 36:747–53 DOI 10.1055/s-0035-1547220
10. Azadeh Shadmehra SMH, Olyaeia G, Talebiana S (2016) Effect of Countermovement and Arm Swing on Vertical Stiffness and Jump Performance. J Contemp Med Sci 2:25–27 ISSN 2413-0516
11. Kobal R, Nakamura FY, Kitamura K, Cal Abad CC, Pereira LA, Loturco I (2017) Vertical and depth jumping performance in elite athletes from different sports specialties. Sci Sports 32:191–196. DOI 10.1016/j.scispo.2017.01.007

12. Wyon M, Allen N, Angioi M E T (2005) Antropometric factors affecting vertical jump height in ballet dancers. J Danc Med Sci 10:250–5
13. Perry S K, Buddhadev H H, Brilla L R, Suprak D N (2019) Mechanical Demands at the Ankle Joint During Saut de Chat and Temps levé Jumps in Classically Trained Ballet Dancers. J Sport Med 10:191–7 10.2147/oajsm.s234289
14. Kulig K, Fietzer A L, Popovich J M (2011) Ground reaction forces and knee mechanics in the weight acceptance phase of a dance leap take-off and landing. J Sports Sci 29:125–31 10.1080/02640414.2010.534807.
15. Meszler A A G (1999) The effect of speed on leg stiffness and joint kinetics in human running. J Biomech 32:1349–53 DOI 10.1016/s0021-9290(99)00133-5
16. Kuitunen S, Komi P V (2002) Knee and ankle joint stiffness in sprint running. Med Sci Sport Exerc 34:166–73 DOI 10.1097/00005768-200201000-00025
17. Kulas A S, Schmitz R J et al (2006) Energy Absorption as a Predictor of Leg Impedance in Highly Trained Females. J Appl Biomech 22:177–85 DOI 10.1123/jab.22.3.177
18. Gamboa J M, Roberts L, Maring J, Fergus A (2008) Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to identify risk characteristics. J Orthop Sports Phys Ther 38:126–36 DOI 10.2519/jospt.2008.2390
19. Ekegren C L, Quested R, Brodrick A (2014) Injuries in pre-professional ballet dancers: Incidence, characteristics and consequences. J Sci Med Sport DOI 17:271–5 10.1016/j.jsams.2013.07.013
20. Costa M S S, Ferreira A S et al (2016) Characteristics and prevalence of musculoskeletal injury in professional and non-professional ballet dancers. Brazilian J Phys Ther DOI 20:166–75 10.1590/bjpt-rbf.2014.0142
21. Schon L C, Weinfeld S B (1996) Lower extremity musculoskeletal problems in dancers. Curr Opin Rheumatol 8:130–42 DOI 10.1097/00002281-199603000-00008

Enter the information of the corresponding author:

Author: Guilherme Augusto Gomes De Villa
Institute: Federal University of Goiás
Street: Avenue Esperança, without number, zip code: 74690-900
City: Goiânia-GO
Country: Brazil
Email: guilhermea1991@gmail.com