DEVELOPMENT OF A TEST PROTOCOL TO IDENTIFY POTENTIAL RISK FACTORS FOR LOWER LIMB INJURIES IN BALLET DANCERS

Signe Boskov Madsen[1], Mark Lake[2], and Mark de Zee[1]

Department of Health Science and Technology, Aalborg University, Aalborg, Denmark[1]
Sport and Exercise Sciences Department, Liverpool John Moores University, Liverpool, U.K.[2]

The aim of the present study was to develop a test protocol to identify potential risk factors for lower limb injuries during ballet jump landings. Two ballet dancers, a beginner level and an advanced level dancer, participated in the study. The dancers performed multiple Sautés in first position, Grand Jeté, and Grand Pas de Chat jump landings on a plantar pressure mat on top of a force platform. The participants wore ballet slipper thongs, while a three-segment kinematic model of the foot was used to provide a more detailed understanding of foot posture during landings, and to investigate how the dancers adapted to the high foot/ankle loadings. Potential risk factors were identified as high free moment peaks, high impact velocities, and improper technique with missing turnouts during landings. Furthermore, there seems a potential to distinguish between dancers' ability levels and associated injury risks.

KEYWORDS: ballet, jump landings, injury risks.

INTRODUCTION: Overuse and lower extremity injuries are a major problem within ballet dance, where ankle sprains, tendon problems in the ankle region, and stress fractures at the metatarsals of the foot are the most common (Allen et al, 2012; Nilsson et al, 2001; Pearson & Whitaker, 2012). Dancers' lower limbs are exposed to enormous loads due to the vertical ground reaction forces (vGRFs), which can exceed their bodyweight seven times during jump landings (Dworak et al, 2006). Consequently, the many hours of work every day, where the goal within ballet is to repeat the movements constantly, may cause excessive loading and damage to the lower limb tissues. To date, detailed descriptions of the foot kinetics and kinematics during ballet jump landings are lacking. Therefore, the aim of the present study was to develop a test protocol to identify potential risk factors for lower limb injuries during ballet jump landings. It was hypothesized that the protocol would be able to detect injury risk factors during ballet jump landings, where high loads are experienced on ballet dancers' lower limbs; even though, little or no shoe cushioning is worn to attenuate those loads.

METHODS: Two female ballet dancers participated in the present pilot study. A beginner level and an advanced level ballet dancer participated to investigate the protocol's applicability within multiple levels of ballet dancing. The beginner level dancer reported to the laboratory once (Participant 2), while the advanced level dancer reported to the laboratory twice (Participant 1.1 and Participant 1.2, respectively) to test for reliability within the protocol. During the test days, a three-segment kinematic model of the foot was used to provide a more detailed understanding of foot posture during landings and investigate how the dancers adapted to the high foot/ankle loadings. Kinematic data of the dominant lower extremity was collected at 250 Hz using an eight-camera three-dimensional motion capture system (Opus, Qualisys AB, Gothenburg, Sweden), while kinetic data were collected at 1000 Hz using a force platform (Kistler). Furthermore, a Footscan® pressure mat (RS-scan International, Olen, Belgium) was placed on top of the force platform and collected the plantar pressure distribution data at 250 Hz. The subjects wore spandex shorts and ballet slipper thongs, so most of the foot was free for markers to be attached directly onto the skin; even though, the foot was supported by pads beneath similar to regular ballet slippers.
The test protocol consisted of a warm-up session and static trials before the data collection began. The performed jumps were 30 Sautés in first position (feet and legs are turned out and facing away from each other) twice. The first three and last three jumps were used for further

analysis. Thereafter, the dancer performed three Grand Jeté, three Grand Pas de Chat, and 30 Sautés in first position twice again, where the first three and last three jumps were used for further analysis.
The four sections of 30 Sautés in first position were introduced as a novel fatigue task by replicating elements of a training session based on ballet observations and feedback. The Grand Jeté and Grand Pas de Chat landings were performed based on pilot work findings together with observations of training practices and coaching advice, which identified those as providing very high loadings on the foot, ankle, and lower limbs.

RESULTS: The initial conditions of impact for the Grand Jeté and Grand Pas de Chat landings demonstrate higher impact velocities for the beginner level dancer compared with the advanced level dancer, where the Grand Jeté landings have higher impact velocities than the Grand Pas de Chat landings (see Table 1).
The subsequent loading measured by vGRF peaks and peak free moments demonstrates similar test-retest results for the advanced level dancer (Participant 1) during the two test days, whereas the beginner level dancer (Participant 2) differentiates from the advanced level dancer. Furthermore, the peak dorsiflexion/plantarflexion ankle moments during landings are higher for the advanced level dancer compared with the beginner level dancer, where the Grand Pas de Chat landings provide the highest ankle moments (see Table 1).

Table 1: Descriptive statistics for the Grand Jeté and the Grand Pas de Chat landings.

Mean (±)	**Participant 1.1**	**Participant 1.2**	**Participant 2**
Grand Jeté vGRF (N/BW)	4.16 (± .60)	4.32 (± .90)	4.55 (± .26)
Grand Pas de Chat vGRF (N/BW)	5.41 (± .83)	5.75 (± .45)	7.40 (± .55)
Grand Jeté Free Moment $\left(\frac{Nm}{\mathrm{BW \cdot H}}\right)$	|.04| (± .01)	|.03| (± .00)	|.06| (± .03)
Grand Pas de Chat Free Moment $\left(\frac{Nm}{\mathrm{BW \cdot H}}\right)$	|.03| (± .02)	|.03| (± .01)	|.12| (± .06)
Grand Jeté Dorsiflexion/Plantarflexion Ankle Moments $\left(\frac{Nm}{\mathrm{BW \cdot H}}\right)$		.81 (± .11)	.64 (± .05)
Grand Pas de Chat Dorsiflexion/ Plantarflexion Ankle Moments $\left(\frac{Nm}{\mathrm{BW \cdot H}}\right)$		.93 (± .04)	.71 (± .03)

The vGRFs for the multiple Sautés in first position indicate a small fatigue aspect from the first three jumps to the last three jumps for the advanced level dancer during both test days. No particular difference is found for the beginner level dancer; however, the starting vGRFs are lower compared with the advanced level dancer. Nonetheless, the jumping height for the participants indicates a fatigue aspect for the advanced level dancer's first test day (Participant 1.1) and the beginner level dancer (Participant 2). However, the advanced level dancer reaches a much higher initial starting height compared with the beginner level dancer (see Table 2).

Table 2: Jumping height in cm measured from a heel marker. The values are a mean of the first three jumps and the last three jumps in a 30 Sautés jump section for all four trials for each participant.

Jumping Height (cm)	**Mean of first three jumps**	**Mean of last three jumps**
Participant 1.1	28.1	26.5
Participant 1.2	28.0	28.0
Participant 2	23.0	21.7
vGRF (N/BW)	**Mean of first three jumps (±)**	**Mean of last three jumps (±)**
Participant 1.1	3.5 (± .4)	3.2 (± .4)
Participant 1.2	3.5 (± .4)	3.3 (± .3)
Participant 2	3.0 (± .4)	3.0 (± .6)

Additionally, the dancers demonstrate differences in plantar pressure peak zones during the multiple Sautés jumps. The plantar pressure peak frame for the first three and last three jumps in a 30-jump Sautés section indicate peak values in the medial side of the forefoot for the majority of the jumps. However, both dancers indicate an element of fatigue during the last three jumps of the sections compared with the first ones according to plantar pressure peaks in zones other than the medial side of the forefoot (see Table 3).

Table 3: Location of the plantar pressure peak zones for the advanced level dancer (Participant 1) and the beginner level dancer (Participant 2) during the first three and last three jumps of a 30-jump Sautés section.

Plantar Pressure Peaks	**First three Jumps**		**Last three jumps**	
Participant 1 (Advanced level dancer)	*Peak foot*	*Support foot*	*Peak foot*	*Support foot*
Medial side of the forefoot	100 %	100 %	100 %	83.5 %
Middle of the forefoot				12.5 %
Heel area				4 %
Participant 2 (Beginner level dancer)	*Peak foot*	*Support foot*	*Peak foot*	*Support foot*
Medial side of the forefoot	50 %	75 %	42 %	67 %
Middle of the forefoot	50 %	25 %	42 %	25 %
Heel area			16 %	8 %

DISCUSSION: The comparative vGRFs and free moment peaks obtained for the advanced level dancer during the two test days indicate good reliability of the developed test protocol. Additionally, the beginner level dancer reaches similar vGRFs for the Grand Pas de Chat landings compared with the female dancer in the study by Dworak et al (2006).

The beginner level dancer demonstrates higher free moment absolute peak values, which indicate increased torsional loadings, which may be a risk factor of injuries. For instance, Willwacher et al (2016) have linked iliotibial band syndrome with high positive free moment peaks, whereas patellofemoral pain syndrome is found related to high negative free moment peaks for runners. To our knowledge, no studies have linked the free moment in ballet dance landings with injury risk factors. However, high free moment peaks may contribute to injury risks in ballet as they do in running, and with different injury risks according to the directions of the peaks.

Another injury risk factor may concern impact velocity, where it has been found that impact velocity increment increases the risk of foot and ankle injuries during axial loadings (Gallenberger et al, 2013). The present study has found higher impact velocities for the beginner level dancer compared with the advanced level dancer. Hence, the advanced level dancer may have developed technical skills to control the landing of the foot with muscular mechanisms and reduce the impact velocity, which may reduce the risk of injuries. Furthermore, the advanced level dancer demonstrates higher ankle moments compared with the beginner level dancer. Landings with a high ankle moment are defined as stiff landings (Zhang et al, 2000), whereas the advanced level dancer is more capable of producing controlled movements.

Regarding fatigue, the advanced level dancer's first test day and the beginner level dancer indicate a fatigue element regarding jumping height. However, the beginner level dancer's starting jumping height is not as high as the advanced level dancer's, which is why fatigue will not be expected in the same degree. Hence, the beginner level dancer does not show the same decrease in vGRF, which also may be a result of utilizing the force sideways instead of vertically. That becomes visual in the plantar pressure distribution peaks, where every jump varies in positioning on the pressure mat - especially in the last three jump-section. Furthermore, the plantar pressure distribution indicates the beginner level dancer's landings on the middle part of the forefoot instead of landing on the medial side of the forefoot. The

improper technique with the missing turnout (landing on the medial side of the forefoot) may be a factor of fatigue as well, which may result in injuries.

CONCLUSION: The preliminary data obtained from the present pilot study indicates that the test protocol is capable of identifying potential risk factors for lower limb injuries during ballet jump landings. The protocol demonstrates reliability during test-retest and comparable results with previous findings. Furthermore, it indicates that it may be possible to differentiate between dancers' ability levels and associated injury risks.
Future studies may include a longitudinal usage of the current study's test battery to see if the predicted injury risk factors also lead to injuries. Furthermore, future studies may take into consideration the floor utilization. Ballet dancers perform on a sprung floor, but the floor used in the present study contains a hard surface in the laboratory, which was not modified for the present study. Hence, the present study's findings may be an overestimation of loading severity; although, the present study may be an underestimation regarding jumping height before jump landings.

REFERENCES

Allen, N. & Nevill, A. & Brooks, J. & Koutedakis, Y. & Wyon, M. (2012). Ballet Injuries: Injury Incidence and Severity Over 1 Year. *The Journal of orthopaedic and sports physical therapy*, 42, 781-90. 10.2519/jospt.2012.3893.
Dworak, L. & Gorwa, J. & Kmiecik, K. & Mączyński, J. (2006). A study characterizing dynamic overloads of professional dancers. Biomechanical approach. *Acta of Bioengineering and Biomechanics*, 7.
Gallenberger, K. & Yoganandan, N. & Pintar, F. (2013). Biomechanics of foot/ankle trauma with variable energy impacts. Annals of advances in automotive medicine / Annual Scientific Conference ... Association for the Advancement of Automotive Medicine. Association for the Advancement of Automotive Medicine. Scientific Conference, 57, 123-32.
Nilsson, C. & Leanderson, J. & Wykman, A. & Strender, L. (2001). The Injury panorama in a Swedish professional ballet company. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*, 9, 242-6. 10.1007/s001670100195.
Pearson, S. & Whitaker, A. (2012). Footwear in classical ballet: a study of pressure distribution and related foot injury in the adolescent dancer. *Journal of dance medicine & science : official publication of the International Association for Dance Medicine & Science*, 16, 51-6.
Willwacher, S. & Goetze, I. & Fischer, K. & Brüggemann, G.P. (2016). The free moment in running and its relation to joint loading and injury risk. *Footwear Science*, 1-11. 10.1080/19424280.2015.1119890.
Zhang, S. & Bates, B. & Dufek, J. (2000). Contributions of lower extremity joints to energy dissipation during landings. *Medicine and science in sports and exercise*, 32, 812-9. 10.1097/00005768-200004000-00014.

ACKNOWLEDGEMENTS: Liverpool John Moores University is acknowledged for hosting the internship period and providing all necessary equipment and facilities in the Sport and Exercise Sciences department. A special appreciation is given to the two participants who participated in the study. Especially the advanced level dancer, Christina Cefai, who reported to the laboratory several times during the pilot tests and main trials, and provided knowledge and guidance regarding ballet dance.