Bilateral Differences in Peak Force, Power, and Maximum *Plié* Depth During Multiple *Grande Jetés*

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A lateral bias has been previously reported in dance training. The aim of this study was to investigate whether there are any bilateral differences in peak forces, power, and maximum knee flexion during a sequence of three *grand jetés* and how they relate to leg dominance. A randomised observational design was selected for the study. Volunteers consisted of 20 female dancers in the last year of pre-professional training. All volunteers completed three different tests to determine leg dominance prior to completing a three *grande jeté* sequence. The lead leg for the jump sequence was randomised. Peak take-off power, relative landing force (BW), and maximum knee flexion angles were measured using a Myotest accelerometer and integrated goniometer. Results indicated that 90% of dancers reported right leg dominance. A significant difference was noted in peak take-off power among the jumps ($p < 0.01$); post hoc test indicated jump 3 was significantly greater than jump 1. Mean maximum take-off knee angles increased over the three-jump sequence with the left leg having a significantly deeper *plié* than the right ($p < 0.01$). Landing data showed an increase in peak force and a decrease in maximum knee angles across the jump sequence. The present data indicate different bilateral strategies during take-off and landing during *grand jetés* in female dancers resulting in increased forces during the jumps on the non-dominant side. These differences need to be addressed by incorporating appropriate modifications in training methodology that eliminates the observed bilateral differences. *Med Probl Perform Art* 2013; 28(1):28–32.

Dance is a complex body action based on a combination of different components,¹ each of which needs to be adequately addressed and developed in a dancer's training programme.^{2,3} All dance movements are reliant on the forces acting on the body from gravity and from interactions between the body and the floor. When a dancer does not utilise a *demi-plié* during a landing, a relatively large vertical ground reaction force (VGRF) is sustained over a short time interval.^{4,5} Landing efficiently, via a controlled deceleration of body segments through a *plié*, can lower ground reaction forces thereby reducing occurrence of injury.^{5–7} Previous research has shown that jump height and VGRF on landing have strong positive correlations with *plié* depth.^{8–10} However, these data were obtained from single jumps.

Due to choreographic needs, the dancer must also be proficient in performing skills on both sides of the body.¹¹ However, Kimmerle¹¹ and Hays¹² have commented that dance training has led to bilateral differences within the body. Widely accepted teaching practices across the different dance forms appear to favour exercises and routines starting on the right side. Consequently, dancers normally have extensive learning experience on one side (typically the right) and most students feel more comfortable favouring that side. In sport, bilateral bias is not perceived as a problem, as one-sided expertise is often considered the norm, i.e. athletes often pitch, serve, kick a field goal from a preferred side.¹¹ Interestingly, there has been little reporting of lower limb bilateral differences in power production,¹³ balance, or muscular patterning,^{14,15} though bilateral differences were noted in VGRF¹⁶ and for strength in the upper limbs,¹⁷ but not for the lower ones.¹⁸

As noted above, published data on jump characteristics in dancers have been obtained from single jumps.^{8–10} However, given that stage dance performances very rarely contain single jumps, the aim of the present study was to investigate whether there are bilateral differences during a three-jump sequence. The *grand jeté* was utilized, which is a split jump often used in a sequence of three jumps and where dancers are expected to generate both height and distance (Fig. 1).

METHODS

A randomised observational experimental design was adopted to assess bilateral differences in peak take-off and landing forces and in maximum knee flexion during a sequence of three *grand jetés* and to evaluate how they relate to leg preference. Each dancer was required to carry out two three-split jump sequences. The lead leg for the jump sequence was randomised. The dependent variables were *plié* depth (degrees), centre of mass take-off power (Watts), and centre of mass landing force (BW).

Subjects

A total of 20 female dancers volunteered for the study (Table 1). All participants were in the final year of a pre-professional contemporary dance programme at a dance conservatoire. The participants were injury free, and each completed and signed an informed consent form and pre-test health questionnaire. The protocol was approved by the authors' university ethics committee prior to commencement of data collection.

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FIGURE 1. *Grand jetés*. (Asya Verzhbinsky, photographer; courtesy of the English National Ballet Company).

Procedures

Pilot Study

The reliability of the Myotest accelerometer and goniometer (Acceltec, Switzerland) were assessed prior to data collection. Eight participants carried out two separate maximal counter-movement jumps with the accelerometer attached to the lower back and the goniometer centred on the lateral aspect of the right knee. Significant Pearson product correlation scores were noted for take-off power ($r=0.92$, $p<0.05$), landing force ($r=0.91$, $p<0.05$), and maximum *plié* depth (knee flexion) ($r=0.89$, $p<0.05$).

Protocol

To determine leg preference, participants were instructed to carry out three tests, two physical and one question.^{13,19,20} The two physical tests consisted of a step-up onto a bench and stomping on a specific spot marked on the floor. The tester phrased the instructions as “step/stomp with any leg.” The leg the participant stepped with and stomped was labelled the participant’s preferred leg. The participant was further asked which leg is their preferred leg, the leg they felt most comfortable to use. The leg that scored two out of the three tasks was designated as the preferred leg.

All participants had a Myotest accelerometer attached to their lower back, centred on L4-5, and its integrated

goniometer to the lateral aspect of their lead/landing knee (Fig. 2). After a 10-minute standardised warm-up, all participants were asked to carry out two trials of three *grande jetés*, with three runs in between each jump. The *grande jeté* is a split leap jump where the dancer leads with one leg, e.g., with the right leg leading, the left leg generates the power during the take-off and the right leg is used during the one-legged landing. Participants were asked to jump as high as possible each time; use of arms was allowed but standardized to third position below shoulder height. All tests were carried out on the same day within a 1-hour slot, prior to the commencement of scheduled dance activity.

FIGURE 2. Placement of Myotest accelerometer and goniometer.

TABLE 1. Participant Descriptive Data

	Age (yrs)	Weight (kg)	Height (cm)	Leg Dominance
Female (n=20)	20 ± 1.74	54 ± 3.2	165 ± 2.5	90% right leg

TABLE 2. Descriptive Data for Landing Force, Take-Off Power and Knee Flexion

		Jump		
		1	2	3
Take-off power (W)	Right	3663 ± 1229*	3882 ± 1336	5364 ± 1746*
	Left	3724 ± 1045	4776 ± 1692	5774 ± 2236
Take-off knee angle (°)	Right	115 ± 26.68	120 ± 26.72	119 ± 26.01
	Left	99 ± 28.08	102 ± 29.58	102 ± 29.57
Landing force (BW)	Right	3.88 ± 0.54	4.19 ± 0.71	4.27 ± 0.82
	Left	4.13 ± 0.93	4.21 ± 1.01	4.29 ± 1.02
Landing knee angle (°)	Right	149 ± 16.84	144 ± 16.91	136 ± 29.23
	Left	139 ± 34.39	135 ± 34.27	135 ± 35.01

*Significant $p < 0.05$.

Data were collected at 1.5 KHz and down sampled to 500 Hz by averaging every three data points. Initial data analyses involved calculation of *plié* depth during the take-off and landing phases of the jumps (maximum angle of knee flexion), power (Watts), and peak force (Newtons), as measured through the centre of mass (CoM) accelerations for all completed jumps. The peak force was further manipulated by converting the Newton data to body weight equivalents (BW) using the equation Newtons/body weight.

Statistical Analyses

The three-jump-sequence data were analysed using univariate ANOVA with leg and jump number as fixed factors; post hoc Scheffe tests were carried out for jump differences and observed power calculated for all variables. Pearson product correlation analysis compared peak landing force and take-off power with the respective maximum knee flexion (*plié* depth) for left and right legs. The alpha level was set at 95% ($p < 0.05$) for all tests.

RESULTS

A significant difference was noted in take-off CoM power between the three jumps for combined data ($F_{2,114}=6.24$; $p < 0.01$, observed power 0.89); post hoc test indicated jump 3 was significantly greater than jump 1; though no significant bilateral difference was noted (Table 2). Mean data for take-off knee angles (Table 2) indicated a non-significant increase over the three-jump sequence, though a significant difference was noted between the legs ($F_{1,108}=10.92$; $p < 0.01$; observed power 0.91). Centre of gravity landing force data showed a non-significant increase in force and a non-significant decrease in knee angles across the jump sequence (Table 2); again, no significant bilateral differences were observed.

Correlation analysis of the left and right legs combined revealed a significant relationship between knee flexion angles during take-off and landing ($r=0.68$, $p < 0.01$) and a small, but significant, negative relationship between knee flexion and landing force ($r=-0.29$, $p < 0.01$). Analysis of indi-

FIGURE 3. Bilateral mean data for take-off indices for the three jumps.

FIGURE 4. Bilateral mean data for landing indices for the three jumps.

vidual legs highlighted differences in laterality; preferred leg leading data demonstrated a positive significant relationship between take-off power and knee flexion ($r=0.26$, $p<0.05$, Fig. 3) and a significant negative correlation between knee flexion and landing force ($r=-0.60$, $p<0.01$, Fig. 4). Non-dominant leg leading data indicated a significant negative correlation between take-off power and knee flexion ($r=-0.29$, $p<0.05$) and a nonsignificant correlation between maximum knee flexion angle and landing peak force.

DISCUSSION

The aim of the present study was to investigate whether there are any bilateral differences in peak take off power and landing force and maximum knee flexion during *grand jetés* and how they relate to leg dominance. Despite the common belief in dance¹¹ that one side of the body is stronger than the other, the current lack of bilateral differences reinforces published data which found a lack of bilateral variation in the lower limbs.^{13-15,21,22} The limb preference in the general population has been associated with skill rather than power and stability movements.²³ In ballet, high skill movements, such as *tendus* and *frappés*, are mainly choreographed for the right leg, whilst the left leg provides the stability and power for movements such as pirouetting and jumping.

Analysis of the three-jump sequence indicated a significant increase in take-off power over the three-jump sequence with a similar though not significant increase in take-off knee angle (*plié* depth) which corresponds to the observed correlation between *plié* depth and take-off power. *Plié* depth during take-off peaked during jump 2 even though there is a subsequent increase in take-off power for jump 3. This suggests the

increase in power output stems from the utilisation of kinetic energy derived from the previous jumps.²⁴ The significantly greater knee angles seen with the right leg leading (left leg take off) did not produce significantly greater take-off power than the other leg. The lack of *plié* depth could be due to either the right leg being stronger and, therefore, less of a *plié* was required to achieve the desired power output, or, as dancers are not used to carrying out one leg *pliés* on this leg, there is a loss in leg stability during deeper *pliés*.²⁵⁻²⁷ The poor correlation between knee angle and take-off power could be due to the fact that only the knee joint was assessed for the purpose of this study; within the *jeté's* kinetic chain, the ankle and hip joints will also contribute to the power output.^{27,28}

The significantly greater knee flexion, or *plié* depth, during landing for the right leg leading during jumps 1 and 2 is possibly a training effect as previously suggested.¹¹ Dancers are trained from an early age to *plié* on landing from a jump and the teaching styles that favour the right leg training could cause this difference in knee flexion. This is clearly seen during the first jump; when the right leg is employed on landing, a much greater knee flexion occurs causing lower peak forces compared to the equivalent data during the same left leg landing. Published data revealed that thigh girth circumferences were greater in the right leg than the left, and this was probably due to the hypertrophical effects of the eccentric muscle action during jump landing.²⁹

It is noteworthy that knee flexion angles on landing for both legs decreased over the three-jump sequence and caused increased peak force. Potential reasons for this are that the last jump has the greatest take-off power and, therefore, was probably the highest, resulting in greater landing force,

and/or that the dancers were focusing on generating take-off power rather than shock-absorption during the landing, which anecdotal evidence seems to support. Dance teachers need to teach technical skills on both legs equally to help reduce the observed imbalance. The previously reported high leg injury rates noted within the dance population³⁰ could be a cause of faulty technique within the landing phase of jumping, and the present study highlights the lack of skill within the nondominant leg during this phase. There is also a need for supplemental training, particularly containing one-leg eccentric muscular actions, that focuses on the landing and take-off aspects of jumping as well as addressing the potential nondominant leg's functional instability thereby allowing a deeper *plié* on landing.

CONCLUSION

Though little bilateral difference was noted within the present study, right leg dominance theory seems to be reflected by the present data, which indicate potential different bilateral strategies during take-off and landing during *grand jetés* in female dancers. Further research is required to assess whether this effect is exaggerated when the dancer is fatigued, and whether an intervention period that emphasises learning with the nondominant leg rectifies differences between legs.

REFERENCES

- Koutedakis Y, Jamurtas A. The dancer as a performing athlete: Physiological considerations. *Sports Med* 2004;34(10): 651–661.
- Ashely L. *The essential guide to dance*, 2nd ed. London: Hodder & Stoughton; 1996.
- Koutedakis Y, Sharp NCC. *The Fit and Healthy Dancer*. Chichester, UK: John Wiley and Sons; 1999.
- Laws K. *Physics and the Art of Dance: Understanding Movement*. New York: Oxford University Press; 2002.
- Lees A. Methods of impact absorption when landing from a jump. *Engl Med* 1981;10(4): 207–11.
- Mizrahi J, Susak Z. In-vivo elastic and damping responses of the human lag to impact forces. *J Biomech Eng* 1982; 104: 63–6.
- Paskevskaya, A., *Both Sides of the Mirror: The Science and The Art of Ballet*, 2nd ed. Pennington: Princeton Book Co; 1992.
- Salci Y, Kentel B, Heycan C, et al. Comparison of landing manoeuvres between male and female college volleyball players. *Clin Biomech* 2004;19(6): 622–8.
- Macintyre J, Joy E. Foot and ankle injuries in dance. *Clin Sports Med* 2000;19(2): 351–468.
- Suter W. One-year changes in hind limb kinematics, ground reaction forces and knee stability in an experimental model of osteoarthritis. *J Biomech* 1998;31(6): 511–7.
- Kimmerle M. Lateral bias in dance training. *J Phys Educ Rec Dance* 2001;72: 34–37.
- Hays J. *Modern Dance: A Biomechanical Approach to Teaching*. St Louis: Mosby; 1981.
- Challis J. An investigation of the influence of bilateral deficit on human jumping. *J Hum Mov Stud* 1998;17(3): 307–25.
- Harrison E, Duenkel N, Dunlop R, Russell G. Evaluation of single-leg standing following anterior cruciate ligament surgery and rehabilitation. *Phys Ther* 1994;74(3): 245–52.
- Lucca J, Kline K. Effects of upper and lower limb preference on torque production in the knee flexors and extensors. *J Orthop Sports Phys Ther* 1989;11(5): 202–7.
- Hawkey A, Lahart I. Effects of bracing dominant and non-dominant ankles on lateral peak impact forces during cutting manoeuvres in male basketball players. *J Sport Sci* 2008;25(s2): s88.
- Hartsell H, Hubbard M, Van Os P. Isokinetic strength evaluation of wrist pronators and supinators: Implications for clinicians. *Physiother Can* 1995;47(4): 252–7.
- Koutedakis Y, Myszkewycz L, Soulas D, et al. The effects of rest and subsequent training on selected physiological parameters in professional female classical dancers. *Int J Sports Med* 1999;20(6): 379–383.
- Cloak R, Galloway S, Wyon M. The effect of ankle bracing on peak mediolateral ground reaction force during cutting manoeuvres in collegiate male basketball players. *J Strength Cond Res* 2010;24(9): 2429–2434.
- Reid DC, Burnham RS, Saboe LA, Kushner SF. Lower extremity flexibility patterns in classical ballet dancers and their correlation to lateral hip and knee injury. *Life Sci* 1991: 189–199.
- Ersoz M, Atalay N, Kumbara F, Akyuz M. Investigation of effect of age, gender and limb dominance on ankle evertor/invertor peak torque ratings of healthy volunteers. *J Phys Ther Sci* 2009;21: 263–267.
- Hoffman M, Schrader J, Applegate T, Kocaja D. Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. *J Athl Train* 1998;33(4): 319–322.
- Sadeghi H, Allard P, Prince F, Labelle H. Symmetry and limb dominance in able-bodied gait: a review. *Gait Posture* 2000;12(1): 34–45.
- Gehri D, Ricard M, Kleiner D, Kirkendall D. A comparison of plyometric training techniques for improving vertical jump ability and energy production. *J Strength Cond Res* 1998;12(2): 85–89.
- Hamilton R, Shultz S, Schmitz R, Perrin D. Triple-hop distance as a valid predictor of lower limb strength and power. *J Athl Train* 2008;43(2): 144–151.
- Myer, G, Ford K, Brent J, Hewett J. The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes. *J Strength Cond Res* 2006;20(2): 345–353.
- Valdez D. Bilateral asymmetries in flexibility, stability, power, strength, and muscle endurance associated with preferred and nonpreferred leg. In: *Applied Physiology and Kinesiology*. Gainesville: Univ of Florida; 2003: p120.
- Hubley C, Wells R. A work-energy approach to determine individual joint contributions to vertical jump performance. *Eur J Appl Physiol Occup Physiol* 2004;50(2): 247–254.
- Wyon M, Allen N, Angioi M, et al. Anthropometric factors affecting vertical jump height in ballet dancers. *J Dance Med Sci* 2006;10(3/4): 106–110.
- Laws H. *Fit to Dance 2—Report of the Second National Inquiry Into Dancers' Health and Injury in the UK*. London: Newgate Press; 2005.