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 grand 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.

Due to choreographic needs, the dancer must also be proficient in performing skills on both sides of the body. However, Kimmerle and Hays 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. Interestingly, there has been little reporting of lower limb bilateral differences in power production, balance, or muscular patterning, though bilateral differences were noted in VGRF and for strength in the upper limbs, but not for the lower ones.

As noted above, published data on jump characteristics in dancers have been obtained from single jumps. 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.
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 countermovement 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. 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.

<table>
<thead>
<tr>
<th>TABLE 1. Participant Descriptive Data</th>
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<td>Age (yrs)</td>
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<td>Female ($n=20$)</td>
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FIGURE 2. Placement of Myotest accelerometer and goniometer.
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-
individual 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 dance\(^{11}\) 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 population 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