

An evaluation of differences in hip external rotation strength and range of motion between female dancers and non-dancers

A Gupta, B Fernihough, G Bailey, P Bombeck, A Clarke, D Hopper

Br J Sports Med 2004;**38**:778–783. doi: 10.1136/bjism.2003.010827

Objectives: To evaluate the differences in hip external rotation (ER) strength and inner, outer, and total hip ER range of motion (ROM) between dancers and non-dancers and between left and right sides in each group.

Methods: Seventy one subjects (34 dancers and 37 non-dancers) volunteered for this study. The strength (truncated range average torque (TRAT), work, and angle specific torque (AST)) of the hip external rotator muscle group, through the full available active hip ER ROM, was evaluated using concentric isokinetic (30°/s) testing on a KinCom dynamometer. Adjustment for lean body mass (LBM) was made for comparison of strength between groups. A two way repeated analysis of covariance was used to compare strength between groups. A two way repeated analysis of variance was used to compare strength between sides and ROM between groups and sides. Bonferroni correction was made for multiple analyses, and significance was accepted at $p \leq 0.05$.

Results: AST at 0°, 20°, 30°, and 40° of hip ER was greater in the dancers than the non-dancers ($p \leq 0.022$). TRAT, work, AST_{0°}, AST_{20°}, and AST_{30°} of hip ER were all greater on the right side than the left ($p = 0.007$) in both groups. Dancers had greater inner ER ROM ($p = 0.013$) and less outer ER ROM than non-dancers ($p \leq 0.001$). There was no difference in total ER ROM between groups ($p = 0.133$). The right side had greater inner ER ($p \leq 0.001$) and total ER ROM ($p \leq 0.001$) than the left in both groups.

Conclusions: Ballet dancers have greater inner range, angle specific strength and inner range ER ROM, demonstrated by a shift in the dancers' strength curves. This shift in the strength curve towards the inner range of hip ER may be an adaptive training response.

See end of article for authors' affiliations

Correspondence to:
Dr Hopper, School of
Physiotherapy, Curtin
University, Bentley, WA
6102, Australia;
d.hopper@curtin.edu.au

Accepted 6 January 2004

Ballet is synonymous with creating effortless movement at the extremes of motion by the human body. Central to it is attaining maximal hip external rotation (ER) to turn the feet and legs out from the hip joint to a 90° position.¹ The five positions of ballet require this turnout position to be achieved through the hip, avoiding compensations at joints above or below the hip.^{2–7} The hip muscles are critical in dancers, as they stabilise the pelvis for balance and generate force while controlling the lower limb during the wide range of dance manoeuvres.^{5, 8, 9}

The emphasis placed on achieving extreme hip ER results in alterations in dancers' biomechanics, as this is an "abnormal" joint position and may lead to tissue injury in the kinetic chain.^{5, 10–12} Epidemiological studies confirm the high incidence of injury in dancers, ranging from 42% to 85%, with most occurring at the lower extremity.^{2, 13–15} Hip muscle strength has been implicated in lower extremity injury in athletic populations.^{16, 17}

Specific training effects for velocity,¹⁸ muscle action, and angle are well established in athletic populations,^{19, 20} but the angle specific strength of the hip external rotators has not been determined in dancers. Velocity specific gain in quadriceps strength measured at 180°/s, and not at lower speeds of 45 and 90°/s, was found in both female and male dancers over a four month period; the gains were made only at functional velocities.²¹ In support of functional strength gains, a study of novice female dancers showed a greater increase in isometric strength of hip flexor, abductor, adductor, and internal and external rotator muscle groups than in a well matched control group over 12 months.²² Furthermore, isokinetic peak torque measurement of concentric hip strength in dancers showed greater torque

production by the external rotators than the internal rotators.^{9, 23} In non-dancers, internal rotator torques have been shown to be greater than the external rotator torques.^{24, 25} These findings may indicate an adaptive response of the external rotators of ballet dancers to their functional demands.

Dancers are unique in their physical and physiological characteristics.²⁶ As strength production is related to the amount of muscle able to generate force, it is essential to normalise for lean body mass (LBM) when comparing non-dancers with dancers.²⁷ The body fat of female ballet dancers has been shown to be 43% lower than that of age and weight matched non-dancers.²⁸ It is essential that dancers have optimal muscle strength to achieve the required extreme hip ER joint position.

There is a paucity of research on differences in hip ER strength and range of motion (ROM) between sides, even though the position of extreme hip ER is vital to the dancer. Investigations of strength differences at the hip between sides have suggested that significant asymmetry is associated with an increased incidence of lower quadrant injury in female athletes.^{16, 17, 29} Side to side differences in dancers' strength have not been investigated.

The purposes of this study were to:

- evaluate if hip ER strength is greater in female dancers than in non-dancers;

Abbreviations: AST, angle specific torque; ER, external rotation; IR, internal rotation; LBM, lean body mass; ROM, range of motion; TRAT, truncated range average torque

- evaluate if there is a difference in hip ER strength between sides in female dancers and non-dancers;
- evaluate if there is a difference in hip ER ROM between female dancers and non-dancers and between left and right sides.

METHODS

This investigation is a cross sectional, two factor, repeated measures design. The first independent variable (between-subjects factor) was the group with two levels: dancers and non-dancers. The second independent variable (within-subjects factor) was the side (repeated measure): left and right.

All dependent variables were measured on left and right sides. Hip external rotator strength was measured as: the truncated range average torque (TRAT; N.m), work (J), and angle specific torque (AST; N.m) at 0°, 20°, 30°, and 40° of hip ER. The dependent variable measured to evaluate hip ER ROM was the truncated hip ER ROM, described as the total ER ROM, outer ER ROM (start ER to 0°), and inner ER ROM (0° to end ER). The position of 0° is the anatomical neutral position of the hip, where, in the prone position, the lower leg is vertical with knee flexed to 90°. LBM was the covariate used to compare strength between groups.

Subjects

Thirty four female dancers training in ballet and contemporary styles volunteered for this study. They were recruited from the West Australian Academy of Performing Arts. Thirty seven age and sex matched non-dancers volunteered from the student population at the Curtin University of Technology, Bentley Campus. Table 1 presents subject profiles.

Inclusion criteria were as follows.

- All subjects were healthy women aged 17–24 years.
- Dancers had trained for a minimum of three years (part or full time).
- Dancers participated for at least 22 hours/week of training for the six months before testing.

Exclusion criteria were as follows.

- Dancers were excluded if they had injury or pain that could be exacerbated by isokinetic testing.
- Dancers were excluded if they had injury or pain that could preclude them from dancing at the time of isokinetic testing.
- Non-dancers were excluded if they had a history of lower quadrant injury or pain.

Each subject was required to attend the KinCom laboratory at Curtin University of Technology on one occasion. An information sheet explaining the aims of the study and strength testing procedure was provided and an informed

consent form signed. The Curtin University of Technology human research ethics committee approved the study.

Equipment

Isokinetic strength was tested on the KinCom 500H dynamometer (Chattecx Corporation, Chattanooga, Tennessee, USA), and data were stored on KinCom software (version 5.3). The KinCom system has excellent reliability for speed and force ($r = 0.94$) and tension ($r = 0.948$).³⁰ Percentage body fat and mass were measured using a Bioelectrical Impedance Analysis Body Fat Monitor (TBF-521; Tanita Tokyo, Japan). This is an accurate measurement of body fat percentage when compared with dual energy x ray absorptiometry ($r = 0.91$, $p = 0.001$).³¹

Testing procedure

After height, weight, and percentage body fat had been measured, the subject completed a standardised warm up by riding a bicycle ergometer for five minutes at a comfortable speed. The subject then stretched the lower extremity muscle groups. The limb to be tested first was randomly assigned by a coin toss. The subject was positioned prone on the plinth (fig 1).

A primary tester aligned the limb to be tested in a neutral hip position, with the axis of the KinCom lever arm aligned with the centre of the shaft of femur and the knee maintained in 90° of flexion. The contralateral limb was placed in abduction of 30–40° (neutral hip flexion/extension). The subject was stabilised by a seatbelt strap (figure of eight) across the sacrum and gluteal folds. Both hands were placed behind the back with face down. The knee was stabilised in a clamp to maintain the centre of rotation about the shaft of the femur and tightened to skin tightness maintaining subject comfort. A second tester placed one hand either side of the femur to keep it in a neutral position in the coronal plane. The gravity correction procedure for the lower limb and lever arm was performed.³²

The end range ER was determined by a series of movements: firstly, the limb was allowed to passively rest into hip ER; secondly, the subject actively externally rotated and, finally, the primary tester applied a gentle overpressure into ER. This was to determine a point at which no further hip ER was available. This angle was entered as the stop angle into the KinCom software and allowed the hip external rotators a full active ROM, overcoming the resistance of the internal rotators. The same method was used to determine the start angle for hip ER. Passive and active ROM measures into hip ER and internal rotation (IR) have been shown to be

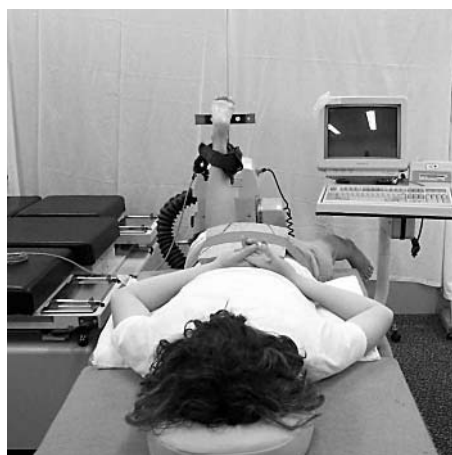


Figure 1 Strength testing position.

Table 1 Subject profiles

	Dancers (n = 34)	Non-dancers (n = 37)
Age (years)	19.1 (1.4)	19.8 (1.6)
Mass (kg)	54.45 (5.1)	59.44 (7.8)
Height (m)	1.65 (0.05)	1.67 (0.06)
LBM (kg)	44.33 (3.33)	43.53 (3.34)
Dance years*	7.6 (0.53)	0

Values are mean (SD).
*Years of dance training.
LBM, Lean body mass.

Table 2 Strength and hip external rotation range of motion dependent variables

Dependent variable	Dancers		Non-dancers	
	Left	Right	Left	Right
TRAT (N.m)	22.21 (1.48)	24.93 (1.55)	20.9 (1.96)	21.24 (1.9)
Work (J)	28.95 (2.07)	37.09 (2.39)	29.74 (2.05)	34.12 (2.07)
AST _{0°} (N.m)	30.57 (2.57)*	33.66 (2.5)*	23.05 (2.18)	25.11 (2.72)
AST _{20°} (N.m)	20.71 (2.03)*	21.73 (1.3)*	14.73 (1.35)	17.13 (2.15)
AST _{30°} (N.m)	15.33 (1.74)*	17.36 (1.25)*	10.29 (0.83)	13.15 (2.04)
AST _{40°} (N.m)	9.73 (1.55)*	12.24 (1.18)*	5.19 (0.72)	1.04 (0.2)
Inner ER ROM (°)	50.68 (2.04)*	57.32 (2.0)*	42.86 (1.84)	52.73 (2.25)
Outer ER ROM (°)	25.47 (2.46)*	28.38 (2.05)*	38.27 (1.56)	37.3 (1.76)
Total ER ROM (°)	76.15 (2.76)	85.71 (2.91)	81.14 (2.33)	90.03 (2.09)

Values are mean (SEM).

*Significantly different ($p \leq 0.05$) from non-dancers.

TRAT, Truncated range average torque; AST, angle specific torque; ER, external rotation; ROM, range of motion.

reliable (all intraclass coefficient (ICC)_(3,1) > 0.95)³³ Before strength testing was started, the subject was familiarised with the direction of movement by the KinCom performing full passive hip IR and ER.

Isokinetic strength testing proceeded, and angular velocity was set at 30°/s. This followed previously used methodology (ICC_(3,1) > 0.90).³³ Active external rotation was followed by active internal rotation. The first contraction in each direction was a 50% effort, followed by efforts of 75% and 90%. Maximal efforts of 100% were repeated to overcome the learning effect,^{20–34} until no improvements in the shape or peak of the strength curves were seen as determined by both testers. The subject was provided with verbal and visual³⁵ feedback of the strength curves between efforts, with the aim of improving performance. A minimum 30–60 second rest period was provided between each effort to allow muscle recovery.^{6–36} The best curve was recorded as determined by the regular shape and highest peak. This was saved on the KinCom software. This strength testing procedure was repeated for the opposite limb with a minimum rest period of two minutes between legs.⁶ At the end of testing, the subject was advised to warm down using the same protocol as for the warm up.

The hip active IR and ER ROM was determined by truncating the strength curves in each direction where angle specific force = 0 N—that is, where $y = 0$. These two points represented the truncated range average force of hip ER. Data, including truncated range average force, angle specific force for ER (at 0°, 20°, 30°, and 40°), and lever arm length (m) for each subject, were entered into a Microsoft Excel (version 5.1) spreadsheet.

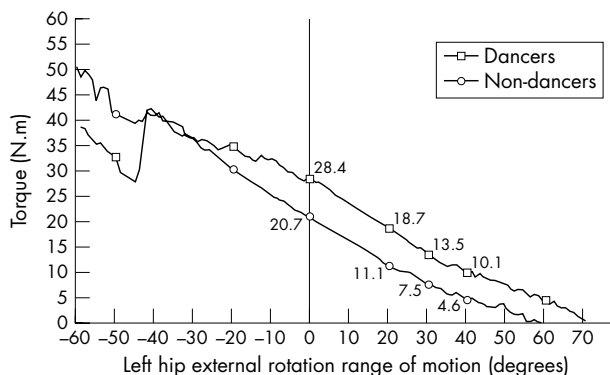


Figure 2 Strength curve for left side of dancers and non-dancers, with angle specific torque values labelled at 0°, 20°, 30°, and 40°.

Calculations

The following calculations were made:

- LBM = (100 - (% body fat)) × (mass (kg))
- TRAT (N.m) = (truncated range average force (N)) × (lever arm (m))
- AST = (angle specific force (N)) × (lever arm (m))
- Work (J) = ((total active hip ER ROM)/180) × π × TRAT
- Mean difference between sides = (R (right) - L (left))
- Mean difference between sides as a percentage = ((R - L)/R × 100)

In the last two calculations, a positive value indicates that the left is less (strength/ROM) than the right, and a negative value that the left is greater (strength/ROM) than the right.

Statistical analysis

Data were analysed using a computerised statistical package (SPSS version 11.5). Descriptive data were obtained for age, weight, height, LBM, and years of dance for both groups. A two way repeated measures analysis of covariance was used to compare strength data between groups. The dependent variables were: TRAT (N.m), work (J), and AST (N.m) at 0°, 20°, 30°, and 40°. Dependent variables for strength comparison between groups were adjusted for LBM. A two way repeated measures analysis of variance was used to compare strength data between sides (N.m) and ROM data between groups and sides (degrees). Bonferroni correction was made for multiple analyses, and significance was accepted at $p \leq 0.05$.

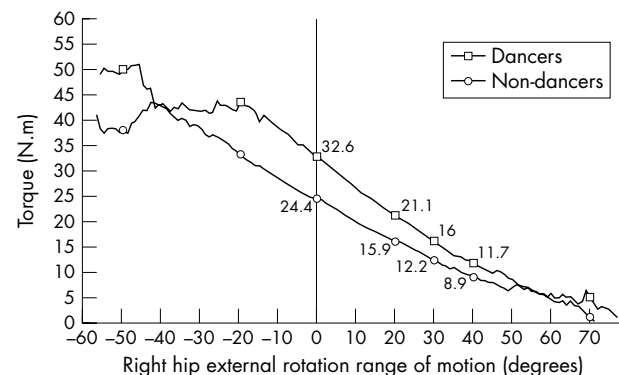


Figure 3 Strength curve for right side of dancers and non-dancers, with angle specific torque values labelled at 0°, 20°, 30°, and 40°.

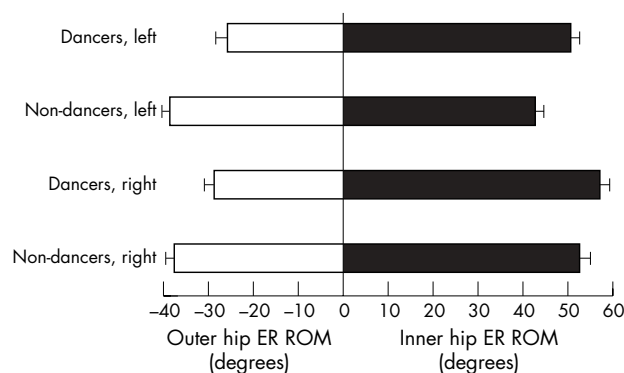


Figure 4 Hip external rotation (ER) range of motion (ROM) (mean and SEM).

RESULTS

Table 2 shows hip ER strength and ROM variables. In dancers, $AST_{0^\circ}^a$, $AST_{20^\circ}^a$, $AST_{30^\circ}^a$, and $AST_{40^\circ}^a$ of hip ER (where superscript a means adjusted for LBM) were significantly greater than in non-dancers ($F_{(1, 68)} = 9.13$, $p = 0.004$; $F_{(1, 68)} = 9.81$, $p = 0.003$; $F_{(1, 63)} = 5.55$, $p = 0.022$; $F_{(1, 45)} = 33.38$, $p \leq 0.001$ respectively). Hip ER strength calculated as $TRAT^a$ and $work^a$ were not significantly different between groups ($F_{(1, 68)} = 0.534$, $p = 0.467$; $F_{(1, 68)} = 0$, $p = 0.989$ respectively). Figures 2 and 3 show the strength curves for left and right sides respectively in each group.

The dancers had significantly greater inner ER ROM ($F_{(1, 69)} = 6.53$, $p = 0.013$), and the non-dancers had significantly greater outer ER ROM ($F_{(1, 69)} = 19.46$, $p \leq 0.001$) (table 3 and fig 4). The total ER ROM was not significantly different between the groups ($F_{(1, 69)} = 2.32$, $p = 0.133$). Dancers had greater hip inner ER ROM of 7.81° (2.74) and 4.59° (3.03) on the left and right respectively.

The right side was significantly stronger than the left side for both dancers and non-dancers for $TRAT$, $work$, AST_{0° , AST_{20° , and AST_{30° ($F_{(1, 69)} = 7.75$, $p = 0.007$; $F_{(1, 69)} = 22.38$, $p \leq 0.001$; $F_{(1, 69)} = 8.62$, $p = 0.005$; $F_{(1, 69)} = 8.63$, $p = 0.004$; $F_{(1, 64)} = 14.17$, $p \leq 0.001$ respectively). The right side was consistently stronger at AST_{0° , AST_{30° , and AST_{40° than the left by a greater margin in dancers than non-dancers (table 3).

The right side had a significantly greater total ER ROM and inner ER ROM than the left side ($F_{(1, 69)} = 25.33$, $p \leq 0.001$; $F_{(1, 69)} = 28.02$, $p \leq 0.001$ respectively; table 4).

DISCUSSION

Dancers exhibit greater angle specific hip ER strength and inner hip ER ROM than non-dancers. Although as a muscle group, the hip external rotators were not found to be stronger ($TRAT$ or $work$) between groups, the dancers were able to generate significantly greater AST in the inner range of hip ER, highlighting the requirements of hip ER during turnout in ballet. This study shows the ability of the dancers to achieve significantly greater hip ER ROM (inner hip ER range) at the expense of hip IR ROM (outer hip ER range). The total hip ROM was similar between the groups (fig 4). This is supported by previous findings on hip rotation ROM in dancers.³⁷⁻⁴² Our finding of greater inner hip ER ROM in dancers (about 8° and 5° on left and right respectively), although statistically significant, is unlikely to be considered clinically significant. The finding is supported by similar findings on hip rotation ROM in dancers⁴³ and runners⁴⁴ where the difference was 10° or less between groups.

In our investigation, the ability of the ballet dancer to achieve extreme hip ER is demonstrated as a shift in the strength curve. There is no greater overall strength of the hip external rotators in the dancers compared with the non-dancers, but they are able to achieve greater strength at angles in the inner range of hip ER (figs 2 and 3). Although it has been noted that the joint position will affect the amount of force generated by a muscle group,⁴⁵ the concept of a shift

Table 3 Side to side differences in dancers and non-dancers for hip external rotation strength dependent variables

Variable	Dancers		Non-dancers	
	Difference	Percentage difference	Difference	Percentage difference
* $TRAT$ (N.m)	3 (1.09)	9.13 (4.33)	0.99 (0.93)	1.41 (4.82)
* $Work$ (J)	8.14 (2.04)	16.04 (5.86)	4.39 (1.71)	9.6 (5.27)
* AST_{0° (N.m)	3.88 (1.89)	10.14 (5.34)	2.99 (1.42)	3.86 (7.04)
* AST_{20° (N.m)	2.02 (1.24)	10.79 (7.83)	4.28 (1.38)	16.59 (7.83)
* AST_{30° (N.m)	2.74 (1.14)	18 (8.12)	4.3 (1.5)	2.46 (16.04)
AST_{40° (N.m)	2.51 (1.47)	0.41 (21.84)	-4.15 (0.75)	-663.97 (159.17)

Values are mean (SEM). The difference between the means (right – left) and percentage difference between the means ((right – left)/right \times 100) are shown. Negative values indicate that left is greater than the right.
 *Right significantly greater than left ($p \leq 0.05$).
 $TRAT$, Truncated range average torque; AST , angle specific torque; ER, external rotation; ROM, range of motion.

Table 4 Side to side differences in dancers and non-dancers for hip external rotation (ER) range of motion dependent variables

Variable	Dancers		Non-dancers	
	Difference	Percentage difference	Difference	Percentage difference
*Inner ER ($^\circ$)	6.65 (1.78)	10.51 (3)	9.86 (2.5)	13.16 (5.74)
Outer ER ($^\circ$)	2.91 (2.08)	1.29 (13.66)	-0.97 (1.57)	-8.81 (5.79)
*Total ER ($^\circ$)	9.56 (2.74)	9.43 (3.22)	8.89 (2.45)	8.95 (2.71)

Values are mean (SEM). The difference between the means (right – left) and percentage difference between the means ((right – left)/right \times 100) are shown. Negative values indicate that left is greater than the right.
 *Right significantly greater than the left ($p \leq 0.05$).

in this curve has not been demonstrated when groups such as dancers and non-dancers have been compared. This shift is significant as it may show a training effect related to angle specific strength.

The observed differences in AST and hip ER ROM may be due to adaptive, physiological changes. These changes may represent a shortening of the hip external rotators and posterior hip joint capsule, with a concomitant lengthening of hip internal rotators and anterior capsule.^{39–41 46} Adaptive changes to the active, passive, and neural subsystems^{47–49} in response to the functional demands of ballet training may be involved. These changes suggest a shift in the strength curve from the anatomical neutral position towards the inner range of hip ER, while the total hip ER ROM remains unchanged. Physiological reasons for greater hip ER ROM in dancers that have so far been discounted are femoral anteversion⁵⁰ and joint hypermobility,⁵¹ neither of which are more prevalent in dancers.

Apart from the characteristics of joint angle, velocity, and muscle action being affected by training, compensatory strategies in the kinetic chain may occur as a result of dancers consistently aiming to achieve extreme hip ER. A compensatory strategy noted to occur is an increase in the dancer's lumbar lordosis as a result of attempting to increase hip ER.¹⁰ This altered biomechanical position is not only seen to increase the available hip ER ROM,³ it may also change the position of the centroid of rotation of the hip and alter the line of pull of the external rotators to allow a change in ER force production. It is acknowledged that the kinetics of the hip, pelvis, and lumbar spine are linked.^{5 52–55} However, the synergistic movement at the pelvis and lumbar spine in relation to triplanar movement at the hip has not been investigated in dancers to confirm the relation of increased hip ER to lumbar lordosis.⁵⁶ This altered hip position may result in the dancers not being in a "true" neutral position relative to non-dancers when lying prone. Hence, the comparison of strength results between dancers and non-dancers is a comparison of functional lumbar neutral positions.

Ballet is inherently a bilateral activity.³ It is assumed that athletes participating in activities that demand symmetrical motor tasks have similar strength in the two lower extremities.³⁷ However, the right hip external rotators of dancers and non-dancers have significantly greater strength (TRAT, work, AST_{0°} and AST_{30°}) than the left, and this asymmetry is more pronounced in dancers. This greater asymmetry may result from dancers favouring one side when training or performing because of limb preference.^{58 59}

Clinically, the predilection for one side in dance specific poses and postures during training may lead to individual side to side differences. This may result in alterations in biomechanics and transference of force in the kinetic chain, muscle imbalances, and deleterious change to the active, passive, and neural⁶⁰ subsystems, which may be associated with injury.^{16 17} The greater difference between the sides in dancers than non-dancers in this investigation may lead to such kinematic changes and be a risk factor for injury.

A feature of this investigation is the use of isokinetic testing, which is the method of choice for demonstrating a shift in the length-tension curve,⁶¹ with respect to non-dancers. Furthermore, testing at a low velocity (30°/s) is reported to have advantages over faster testing speeds. More deficits in muscular function are revealed, as the lower speed allows the subject to generate a higher maximal force.⁵⁷ Low speeds more closely replicate the role of the hip external rotators, as they maintain the hip in ER rather than act in high speed movements like the quadriceps and hip extensors in jumping or landing. Testing in a hip neutral position more closely replicates the upright position of the dancer,²⁴

What is already known on this topic

Ballet dancers have greater strength at angles of inner range hip external rotation range than non-dancers. This may be an adaptive response to the requirement of extreme hip external rotation.

maintaining the role of the external rotators to create ER rather than IR, which occurs when the hip is flexed to 90° as in other testing positions.^{24 62 63} Measuring force through the full available active hip ER ROM for each subject, rather than using arbitrary limits to hip rotation ROM for all subjects, allowed analysis of the full strength curve. Finally, providing visual^{19 35} and verbal feedback encouraged subjects to maximal effort.

The heterogeneity of the dance subjects is a limitation of this investigation, as they were from both ballet and contemporary styles of dance. Testers were not blinded to the group allocation, leading to possible systematic error, whereby visual and verbal feedback and interpretation of the graphs may not have been equal between all subjects tested. A further limitation was the difficulty of controlling the time and day of testing. This may have affected the LBM measurements. Strength testing about the hip inherently has the problem of adequate thigh stabilisation to avoid compensatory strategies that may affect the strength curves. Finally, force generated about the hip joint may not represent the actual strength produced, as the axis of rotation used is the shaft of femur, not the true axis of rotation about the hip joint.

Clinical findings of this study are:

- Dancers show greater hip ER strength into extremes of hip ER.
- Greater hip ER ROM is not the sole prerequisite of a dancer, rather strength and ROM at angles specific to the demands of ballet are required.
- Dancers exhibit a greater right to left side strength difference than non-dancers and this greater asymmetry must be kept in mind when assessing a dancer's strength as it shows their preference of a single limb. This asymmetry may contribute to alterations in the kinetic chain and may be a risk factor for injury.
- Musculoskeletal assessment or screening of dancers must include strength measurements at angles specific to the demands of the task, rather than assume overall strength differences to exist between trained and untrained populations for specific muscle groups.

Suggestions for future research are investigation of the strength changes that may occur prospectively, establishment of normal side to side differences as a baseline for comparison with other dance and athletic populations, and development of dance screening protocols to include accurate angle specific strength and ROM testing protocols.

ACKNOWLEDGEMENTS

We acknowledge the expert advice of Mr Geoff Strauss in isokinetic testing procedures on the KinCom dynamometer and Dr Kathy Briffa for her assistance with statistical analysis.

Authors' affiliations

A Gupta, B Fernihough, G Bailey, P Bombeck, D Hopper, School of Physiotherapy, Curtin University, Bentley, WA 6102, Australia
A Clarke, Curtin University, Bentley, WA 6102, Australia

Conflict of interest: none declared

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