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Case report

Three-Dimensional Analysis of a Ballet Dancer with Ischial Tuberosity Apophysitis. A Case Study

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Abstract
The purpose of this case study was to describe the three-dimensional biomechanics of common ballet exercises in a ballet dancer with ischial tuberosity apophysitis. This was achieved by comparing kinematics between the symptomatic (i.e. ischial apophyseal symptoms) and contralateral lower limbs, as well as via reported pain. Results suggest consistent differences in movement patterns in this dancer. These differences included: 1) decreased external rotation of contralateral hip, hence a decreased hip contribution to 'turn out'; 2) increased contralateral knee adduction and internal rotation; 3) an apparent synchronicity in the contralateral lower limb of the decreased hip external rotation and increased knee adduction; and 4) minimal use of ankle plantar/dorsiflexion movement for symptomatic side. Pain related to the left ischial apophysitis was associated with reduced amplitudes especially in fast ballet movements that required large range of motion in flexion and adduction in the left hip joint. These findings suggest that ischial apophysitis may limit dancer's ballet technique and performance.

Key words: Sports injuries, dance, case study, biomechanics.

Introduction

Musculoskeletal injuries are considered to be very common among dancers. Incidence of injury varies from 17% to 95 % (Bronner et al., 2003). It has also been stated that injury incidence is 4.4 per 1000 hours, and 6.8 injuries per dancer within a year (Allen et al., 2012). Overuse injuries are predominant, such as tendinosis, stress fractures and apophyseal injuries that manifest at the lower limb, hip and spine (Allen et al., 2012; Hincapié et al., 2008; Jacobs et al., 2012; Motta-Valencia, 2006; Steinberg et al., 2013). Thus, mastering dance technique requires repetitive physical loading that may exceed the limits of anatomical and physiological capabilities, and lead to injuries. Further understanding of the biomechanics of dance is essential to identify the specific musculoskeletal demands placed on the body and to uncover pathomechanics that may lead to injury (Motta-Valencia, 2006). To reduce both the injury incidence and prevalence it is crucial to enhance effective injury prevention strategies, rehabilitation, and biomechanically safe and efficient technique training practices as well dance pedagogy.

Research to date in dance biomechanics has focused on impact (such as jumps) and high pressure (e.g. pirouettes) movements as well as describing typical ballet movements. Other areas of interest include point shoes, motor control, dancing regimens, dance floor, motor skills of novice and professional dancers, and differences between barre work and center floor (Kadel and Couillandre, 2007; Koutedakis et al., 2008; Krasnow et al. 2011; Krasnow, 2012; Laws, 1985; Ward 2012). To our knowledge, there is little research on the effect of the commonly found apophyseal injury on dancer's movement patterns and the challenges these injuries may pose to technical demands of dance and dance pedagogy. In the present case report, the aim is to compare the kinematics of the symptomatic (i.e. ischial apophyseal symptoms) and contralateral lower limbs, as well as associated reported pain of a ballet dancer with a left ischial apophysitis during ballet exercises. The purpose of this study is to inform dancers, their teachers and health professionals about movement changes that may present with this common but complex and underreported injury in a dance context.

Case report

Subject

A 27-year-old professional male classical dancer with left ischial apophysitis volunteered to participate in the study. The diagnosis was made by a specialist physiotherapist with relevant PhD, supported by clinical history, physical assessment, MRI findings and medical specialist's (sports physician) opinion. The participant also presented with concomitant, but less symptomatic, left heel and achilles pain, and longstanding right groin pain primarily at the origin of adductor muscles (i.e. right pubis and the symphysis pubis).

The pain in the ischial tuberosity had been ongoing for about 6–8 months, and was described as vague. Self-reported pain via numeric rating scale (NRS; self-reported pain score in integers: 0–10) (Ferreira-Valente et al., 2011; Jensen et al., 1986) was usually 3, and 6 on its highest. The pain was aggravated mainly by stretching and during rapid movements. The participant reported that both the injuries at the pelvis had been treated with relative rest to relieve the pain (e.g. modification in training load and limitation of pain aggravating activities), therapeutic exercises, ice and ultrasound. The dancer stated that the injuries restricted range of motion (ROM) in general.

Data collection

Data collection took place on an indoor synthetic track surface in the Motion Laboratory at the University of the Sunshine Coast (Australia). Prior to the testing, the participant was provided with a Research Project Information

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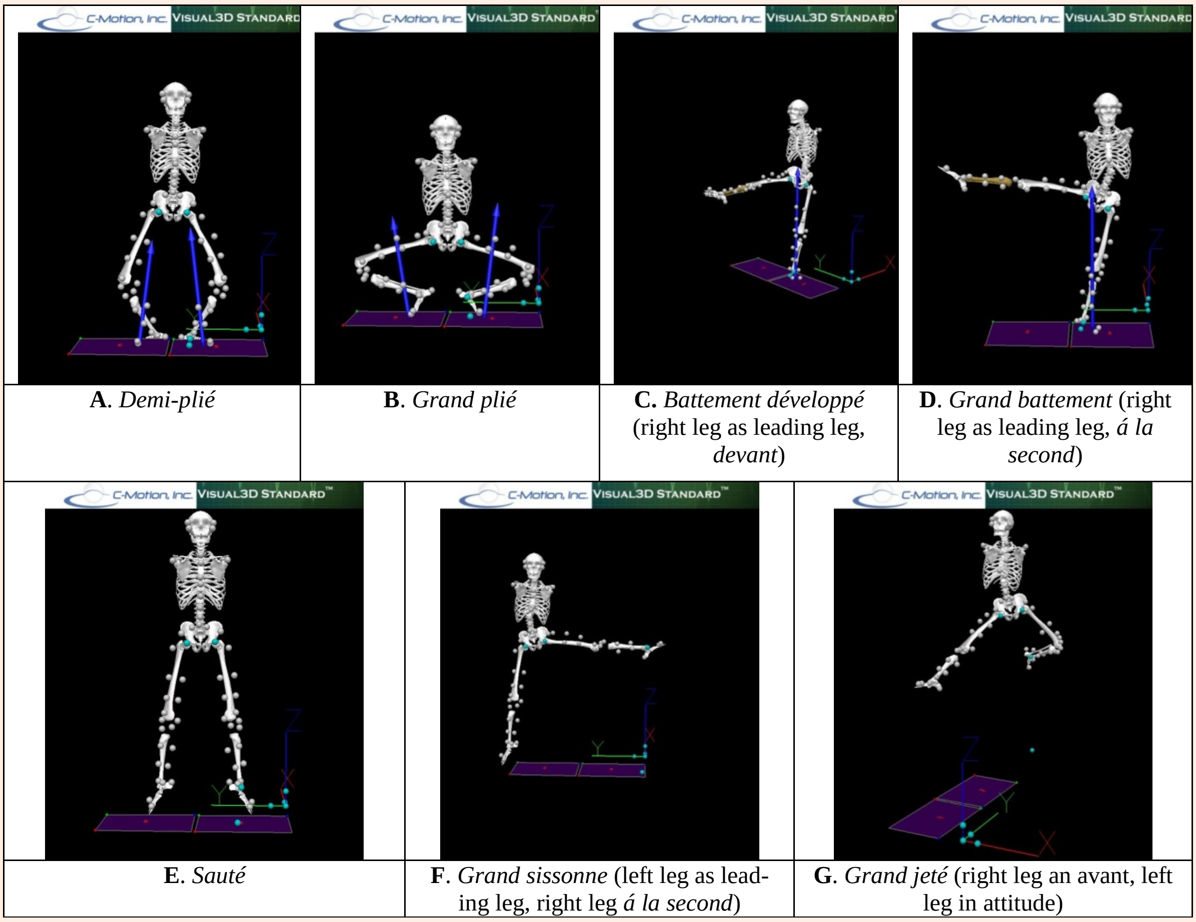
Sheet and given the opportunity to ask questions about the test protocols before signing a consent form. The participant also completed a medical screening questionnaire prior to the test. The study was approved by the institutional Human Research Ethics Committee.

Three-dimensional (3-D) kinematic data were collected at a sampling rate of 500 Hz, with a nine-camera motion analysis system (Qualysis Motion Capture System; Qualysis AB, Gothenburg, Sweden). Kinetic data (ground reaction force, GRF, x, y, z) were recorded via two force plates (Bertec; Bertec Corporation, Ohio, USA), sampling at 2000 Hz. Anthropometric parameters (including height and weight) were also measured.

A total of 40 individual retro-reflective markers (16 mm) and four clusters (4 markers each) were attached at specific anatomical locations on the head, upper and lower limbs, and trunk according to the protocol of the University of the Sunshine Coast. Specific marker sites were right and left temples, right and left zygomatic bones, right and left lateral sides of acromions, manubrium of sternum and inferior part of sternum (sternal body), 7th cervical spinous process (C7), 6th and 12th thoracic spinous process (T6, T12), 2nd and 4th lumbar spinous process (L2, L4), sacrum (S2), right and left posterior and anterior superior iliac spines, both the greater trochanters, clusters of markers for right and left thigh segments, both the lateral and medial femoral epicondyles in the right and left, right and left lateral and medial sides of tibial condyles, right and left tibial tuberosities, cluster of markers for shanks, right and left malleoli, both the heels (LHEEL, RHEEL) and 1st and 5th metatarsal bones in the right and left. (Bishop and Kerr, 2010) The acromion landmark was modified from lateral acromion to the spine of scapula (~ posterior to the acromioclavicular joint) to improve marker tracking, particularly as the arms were held in second position throughout the exercises.

The test battery commenced with a static capture (standing in anatomical position) that was followed by dynamic captures (i.e. ballet tasks). The subject performed a total of seven different tasks including *demi-plié* (i.e. small flexion of the knees), *grand plié* (i.e. full flexion of the knees), *battement développé* (i.e. gradual unfolding of the leg to front, side and back), *grand battement* (i.e. rapid lift of the straight held gesture leg into hip level or higher to front, side and back), *sauté* (small jump), *grand sissonne (à la côté)* (i.e. jump with elevation of the gesture leg to side), and *grand jeté (en avant)* (i.e. large jump where legs are thrown to 90 degrees, gesture leg in front) (see Figure 1). The selected elementary ballet movements represent the most common vocabulary used in ballet dance technique, depict weight bearing (both on two feet and on one foot) and require variation in range of motion, complexity, force and velocity.

All single lower limb exercises were repeated on both legs. Five representative trials of each task were performed, unshod, in a slightly separated heel position in



A. *Demi-plié*
B. *Grand plié*
C. *Battement développé* (right leg as leading leg, *devant*)
D. *Grand battement* (right leg as leading leg, *á la second*)
E. *Sauté*
F. *Grand sissonne* (left leg as leading leg, right leg *á la second*)
G. *Grand jeté* (right leg an avant, left leg in attitude)

Figure 1. Images of the ballet battery of seven tasks undertaken by the subject.

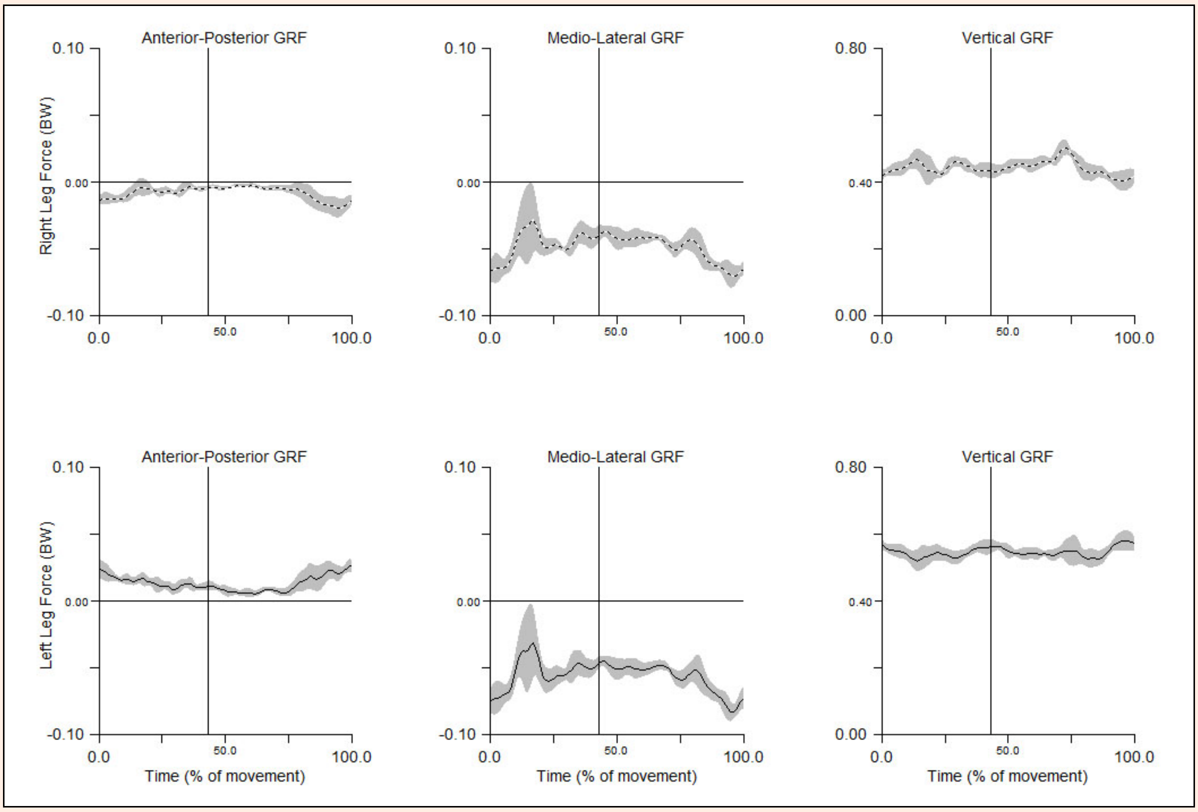


Figure 2. Ground reaction forces (GRF, scaled to body weight BW) during *demi-plié* of the right (contralateral, shown along top dotted line) and left (symptomatic, shown on bottom solid line) lower limbs. The vertical line indicates timing at the bottom of the *demi-plié*. Positive values on the graphs indicate transfer of weight towards that variable.

the first position of the feet. Hands were held in the second position throughout the exercises. Seven attempts were allowed to obtain five representative trials. Acceptable trials were defined as those in which the participant completed the task on the force plates as required.

To minimize the risk of further injury, the participant was given the opportunity to warm-up prior to and after the attachment of the markers, and to cool down after the test. Rest intervals were allowed for 30 seconds between the tasks as required. The participant was also given a practice trial before each task, to be more familiar with the surface and the force plates. After completing each task, the participant reported pain via NRS.

Data processing and analysing

Raw data for markers (trajectories) were labelled according to respective anatomical landmarks and trimmed of redundant pre and post task data. Gaps under 100 ms (i.e. 50 frames at 500 Hz) were gap-filled. The 3D coordinate data were then modelled using standard biomechanical software (Visual3D; C-motion 4.96.3, Inc. Maryland, USA) to construct a 7 segment rigid body model of the pelvis and lower limbs (left and right: thigh, shank and foot). Data were smoothed using a 4 Hz second order low pass digital filter prior to the construction of the model. A global reference system (GRS) was established with the positive y-axis in the intended direction of travel (anterior-posterior), the x-axis perpendicular to the intended direction of travel (positive direction to the right, mediolateral) and the positive z-axis pointing vertically upwards (vertical). The movement phases were defined by start and end points (creating movement events such as start and end of *plié*, deepest point of *plié*). Pain (NRS) and the following kinematic and kinetic parameters were defined for analysis: joint angle (6 DOF ankle, knee and hip; pelvis), and ground reaction force (3D; x, y and z axis).

Results

Ground reaction force, weight-bearing

Data reflecting relative weight-bearing were produced for the three ballet movements that were performed on both feet: *demi-plié*, *grand plié*, and *sauté*. In all three of these movements, weight-bearing was asymmetrical. Generally, increased or preferential weight-bearing was observed on the left lower limb, for example in *demi-plié* (see Figure 2).

Kinematics: Joint angles of hip, knee and ankle

With the comparison of the kinematics, dissimilarities between lower limbs were observed consistently in both open and closed kinetic chain tasks but particularly in the closed chain tasks. Differences in movement planes were noticeable particularly in frontal (particularly knee adduction / abduction) and horizontal (particularly hip rotations) planes. Differences in sagittal plane movements were observed, particularly in dorsiflexion. A reduction in movement amplitude (i.e. range of movement, height of the gesture leg) of the left hip flexion was noted during

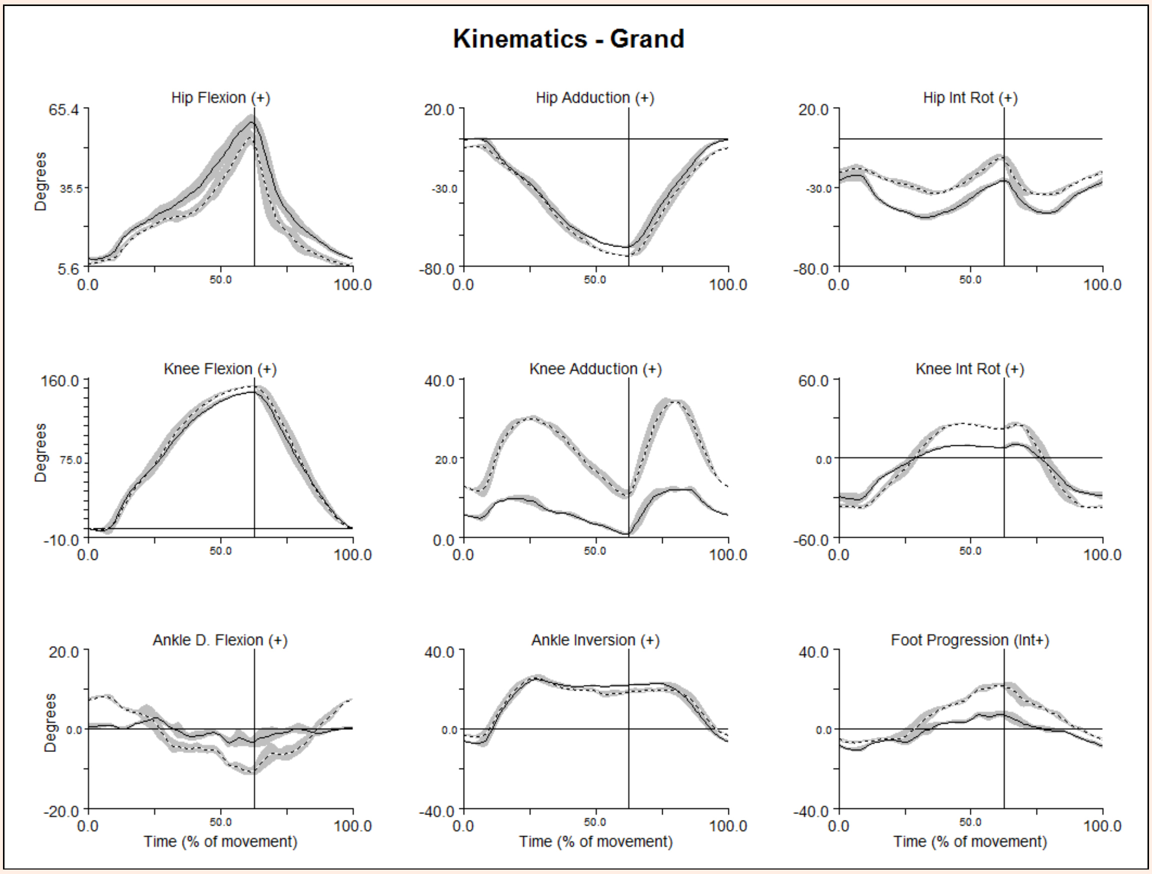


Figure 3. Kinematic data (joint angles of hip, knee and ankle) demonstrating consistent differences between sides for *grand plié*. Note: Right side: dotted line (contralateral), Left side: solid line (symptomatic); shaded area indicates mean +/- 2SD; + indicates positive values on y-axis for given movement (for example, knee flexion is zero degrees into a positive direction, knee extension from zero into negative); the vertical line indicates timing at the deepest point of the *grand plié.*
During *grand plié*, notable consistent differences in joint angles can be observed:
A: decreased right (contralateral – dotted line) hip external rotation (e.g. decreased contribution to "turn out").
B: increased right (contralateral) knee adduction and internal rotation (deepest portion of the plié, decreased contribution to "turn out").
C: differences in ankle position (e.g. minimal use of ankle plantar/dorsiflexion movement for more symptomatic side).
D: Note the apparent synchronicity of decreased right hip external rotation and increased right knee adduction from ~50%-75% of the *grand plié*.

grand battement en avant and *grand jeté en avant.* Intertwined recurring dissimilarities were apparent in rotations: as increased external rotation was observed in the left hip, the right knee showed increased knee adduction and internal rotation (see Figure 3).

Kinematics: Position of the pelvis

Increased anterior tilt in the pelvis was also frequently apparent throughout most of the test battery. Consistent pelvic tilt strategies were observed during higher amplitude movements (e.g. battement développés and grand battements), where posterior tilt was apparent in *devant* (i.e. front) and *á la second* (i.e. side), and anterior tilt in *á la derriere* (i.e. back). The *grand jeté en avant* highlighted a different movement strategy (see Figure 4) where left hip flexion (i.e. leading lower limb) was performed in posterior pelvic tilt, whereas right hip flexion was associated with anterior pelvic tilt.

Pain (numeric rating scale, NRS)

Pain increased with the progress of the test battery, within the limits of the participant's usual practice and performance (see Table 1). Prior to commencement and during the *demi-plié,* the self-reported pain was 1 (NRS 0–10). It increased in *grand plié* to 3 during the extension phase of the movement. Pain was maintained and plateaued at 3 during the *battement développé;* with the exception of the left leg *à la derriere* (i.e. as leading leg), which resulted in pain of 5 in the right pubic area. Similarly, in the *grand battement* series, pain was 2 in movements other than leading leg. Directions of *devant*, and *à la second* reproduced pain of 4 in the left as leading leg. During *à la derriere* pain decreased to 3. In *sauté* and *sissonne* the pain was reported to be 3. While performing *grand jeté en avant* pain increased: pain was 4 while right leg in front (around the pubic bone), and 5 while having left leg in front (ischial tuberosity). It is noteworthy that the symptomatic lower limb (i.e. the left; *en avant*) in *grand jeté* reached a reduced ROM of only 45 degrees of hip flexion, while the right was executed into 90 degrees.

Discussion

This article focused on the three-dimensional biomechanics of ballet exercises. Asymmetrical ground reaction forces were consistent with preferential weight-

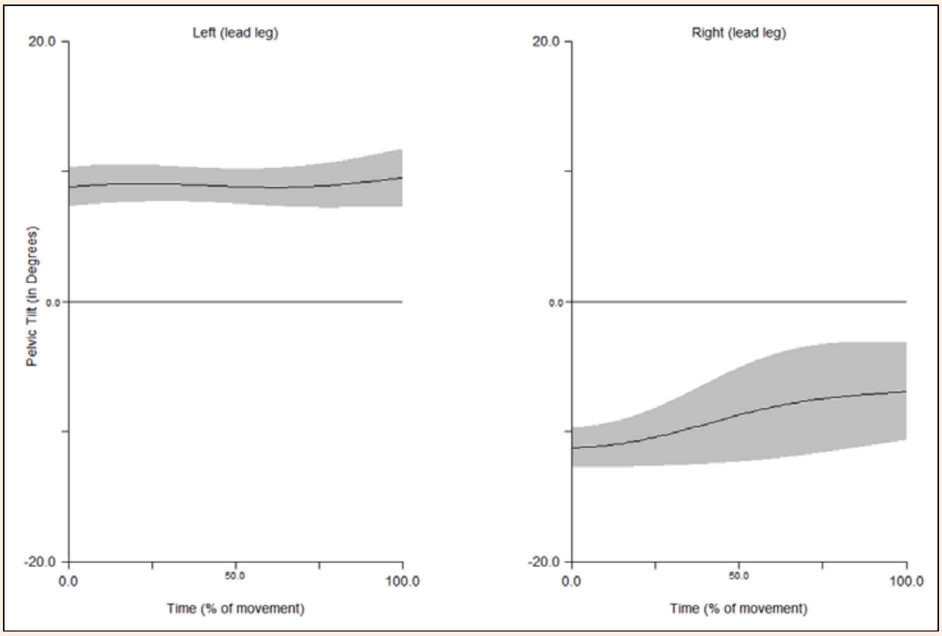


Figure 4. The position of the pelvis during *grand jeté en avant,* where positive values indicates posterior pelvic tilt, and negative indicates anterior pelvic tilt.

Table 1. Self-reported pain via numeric rating scale (NRS, 0–10) during the ballet movements. NRS refers to the pain experienced at the left ischial apophysitis (with the exception of * that indicates pain in the right pubic bone).

BALLET MOVEMENT	NRS	
demi-plié	1	
grand plié	3	
sauté	3	
	LEFT (as leading leg)	**RIGHT (as leading leg)**
battement développé		
• *devant (front)*	3	3
• *á la second (side)*	3	3
• *á la derriere (back)*	3	5 *
grand battement		
• *devant (front)*	4	2
• *á la second (side)*	4	2
• *á la derriere (back)*	3	2
grand sissonne	3	3
grand jeté		
• *right, en avant (front)*		4 *
• *left, en avant (front)*	5	

bearing on the left (i.e. symptomatic) lower limb. In addition, differences between the symptomatic (i.e. left) and contralateral (i.e. right) lower limb kinematics were observed in all movement planes. Both increased knee adduction and medial rotation, and to a lesser extent anterior tilt in the pelvis, were consistent with commonly described compensatory movements for inadequate and uneven hip turnout (lateral rotation). These compensatory strategies in the kinetic chain refer to anterior tilt in the pelvis, external rotation of the knee and hyper pronation (Bennell et al., 1999; Grossman et al., 2008; Hamilton et al., 2006; Negus et al., 2005) that could be observed in this study as well.

Increased anterior tilt in the pelvis was also frequently apparent throughout most of the test battery. Consistent pelvic tilt strategies were observed during (e.g. battement développés and grand battements), where posterior tilt was apparent in *devant* and *á la second*, and anterior tilt in *á la derriere*. The position of the pelvis during the higher amplitude movements were consistent with the previous literature that suggests that in similar positions such as *grand rond de jambe en l`air* and *développé arasbesque* the pelvis should attend actively with the leading leg when 90 degrees or more is accomplished; either in tilting posteriorly (while leading leg is in front), anteriorly (leading leg in back), or laterally (leading leg to the side) (Wilson et al., 2007). On the contrary *grand jeté en avant* indicated a different movement strategy in the gesture leg. This might be in relation to the traction forces, rapid movement and demand of large range of motion. Overall, pain was aggravated with progress of the test battery, and it was at its highest during fast movements with the requirement of large amplitude (i.e. *grand jeté avant* NRS 5, *grand* *battement devant* and *à la second* NRS 4) in the gesture leg that exerted traction on the apophyseal area (Adirim and Cheng, 2003; Eich et al., 1992; Kujala et al., 1997; Ogden, 2003; Paluska, 2005).

It is essential to acknowledge that specific motion analysis and movement description concerning the ischial apophysitis must be interpreted whilst remaining mindful of the other injuries in the dancer. However, this is not an unusual array of concomitant issues and a case study offers an ideal mode for exploration of this complex presentation. It is also important to note that the tasks performed in this study were relatively elementary ballet movements. Perhaps more vigorous and complex tasks, or movements with larger ROM (range of motion), may produce different movement changes than those presented here. It is acknowledged that the limitations of this case study (e.g. one participant with multiple injuries) demands that the reader should only generalize findings with caution. As with all case studies, the methodology does not allow for demonstration of causation or association.

The dance medicine literature is heterogeneous and a young discipline (Hincapié et al., 2008). Large gaps remain in the literature with respect to specific dance injuries and their relationships, including widely varying prevalence and incidence rates and a lack of published evidence on injuries. This may be due to a dance culture that underreports injury, difficulties in recruiting elite dancers for research or the difficulties in controlling experimental variables and cohort homogeneity in a target population with high rates of concomitant pathology. In the face of these challenges to clinical research in dance, case studies offer opportunities to break new ground for research evidence, and describe these complex situations to inform injury prevention and rehabilitation.

Conclusion

During the test the pain related to the left ischial apophysitis was associated with reduced amplitudes especially in fast ballet movements that required large range of motion in flexion and adduction in the left hip joint. Several recurring dissimilarities between the lower limbs could be found in the joint angles. Thus the case study indicates that there might be differences in movement patterns between the limbs in a dancer with ischial apophysitis. This may limit dance technique and performance.

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References

Adirim, T.A. and Cheng, T.L. (2003) Overview of injuries in the young athlete. *Sports Medicine* **33,** 75-81.

Allen, N., Nevill, A., Brooks, J., Koutedakis, Y. and Wyon, M. (2012) Ballet injuries: injury incidence and severity over 1 year. *Journal of Orthopaedic & Sports Physical Therapy* **42**, 781-790.

Bennell, K., Khan, K.M., Matthews, B., De Gruyter, M., Cook, E., Holzer, K. and Wark, J.D. (1999) Hip and ankle range of motion and hip muscle strength in young novice female ballet dancers and controls. *British Journal of Sports Medicine* **33**, 340-346.

Bishop, S. and Kerr, A. (2010) *Equipment Protocol for QUALISYS 3D Motion Capture System.* University of the Sunshine Coast, Australia.

Bronner, S., Ojofeitimi, S. and Rose, D. (2003) Injuries in a modern dance company: effect of comprehensive management on injury and time loss. *American Journal of Sports Medicine* **31,** 365-373.

Eich, G.F., Babyn, P. and Giedion, A. (1992) Pediatric pelvis: radiographic appearance in various congenital disorders. *RadioGraphics* **12,** 467-484.

Ferreira-Valente, M.A., Pais-Ribeiro, J.L. and Jensen, M.P. (2011) Validity of four pain intensity rating scales. *Pain* **152**, 2399-2404.

Grossman, G., Waninger, K.N., Voloshin, A., Reinus, W.R., Ross, R. and Bibalo K. (2008) Reliability and validity of goniometric turnout measurements compared with MRI and retro-reflective markers. *Journal of Dance Medicine and Science* **12**, 142-152.

Hamilton, D., Aronsen, P., Løken, J.H., Berg, I.M., Skotheim, R., Hopper, D., Clarke, A. and Briffa, N.K. (2006) Dance training intensity at 11–14 years is associated with femoral torsion in classical ballet dancers. *British Journal of Sports Medicine* **40**,299-303.

Hincapié, C., Morton, E. and Cassidy, D. (2008) Musculoskeletal injuries and pain in dancers: a systematic review. *Archives of Physical Medicine and Rehabilitation* **89,** 819-1829.

Jacobs, C., Hincapié, C. and Cassidy, D. (2012) Musculoskeletal injuries and pain in dancers: a systematic review update. *Journal of Dance Medicine and Science* **16**, 74-84.

Jensen, M.P., Karoly, P. and Braver, S. (1986) The measurement of clinical pain intensity: a comparison of six methods. *Pain* **27**,117-126.

Kadel, N. and Couillandre, A. (2007) Kinematic, kinetic, and electromyographic (EMG) analysis comparing unsupported versus supported movements in the ‘en pointe’ position. *Journal of Dance Medicine and Science* **11**, 23. Abstract.

Koutedakis, Y., Owolabi, E. and Apostolos, M. (2008) Dance biomechanics: a tool for controlling health, fitness, and training. *Journal of Dance Medicine and Science* **12,** 83-90.

Krasnow, D. (2012) *An investigation of grand battement devant at barre, centre and in motion using kinematics and electromyography*. Doctoral thesis, University of Wolverhampton, Wolverhampton.

Krasnow, D., Wilmerding, V., Stecyk, S., Wyon, M. and Koutedakis, Y. (2011) Biomechanical research in dance: a literature review. *Medical Problems of Performing Artists* **26,** 3-23.

Kujala, U.M., Orava, S., Karpakka, J., Leppävuori, J. and Mattila, K. (1997) Ischial tuberosity apophysitis and avulsion among athletes. *International Journal of Sports Medicine* **18**, 149-155.

Laws, K. (1985) The biomechanics of barre use. *Kinesiology for Dance* **7,** 6-7.

Motta-Valencia, K. (2006) Dance-related injury. *Physical Medicine & Rehabilitation Clinics of North America.* **17**, 697-723.

Negus, V., Hopper, D. and Briffa. (2005) Associations between turnout and lower extremity injuries in classical ballet dancers. *Journal of Orthopaedic & Sports Physical Therapy* **35**, 307-318.

Ogden, J.A. (2003) *Skeletal injury in the child.* Springer-Verlag, New York.

Paluska, S.A. (2005) An overview of hip injuries in running. *Sports Medicine* **35**, 991-1014.

Steinberg, N., Siev-Ner, I., Peleg, S., Dar, G., Masharawi, Y., Zeev, A. and Hershkovitz, I. (2013) Injuries in female dancers aged 8 to 16 years. *Journal Athletic Training* **48**, 118-123.

Ward, R.E. (2012). *Biomechanical perspectives on classical ballet technique and implications for teaching practice.* Doctoral thesis, University of New South Wales, Sydney.

Wilson, M., Ryu, J-H. and Kwon, Y-H. (2007) Contribution of the pelvis to gesture leg of range of motion in a complex ballet movement: grand rond de jambe en l` air en dehors. *Journal of Dance Medicine and Science* **11**, 118-123.

Key points

- The pain related to the left ischial apophysitis was associated with reduced amplitudes especially in fast ballet movements that require large range of motion. This may affect to the lower limbs kinematics, and limit dancer's technique and performance.
- Compensatory strategies in the kinetic chain, differences in the joint angles between the lower limbs, traction forces, velocity and amplitude demands should be taken in consideration while training and rehabilitation of the ischial apophyseal injury within classical ballet.

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