Dissertation

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The Impact of Passive Hip Rotation on the Quality of the Back Squat Pattern: A Cross-Sectional Study

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Abstract

Research has shown that dancers are often muscularly weak and demonstrate abductor-adductor and hamstring-quadriceps ratio imbalances. Furthermore, flexibility discrepancies between the internal and external range of movement (ROM) in the hip joint have been observed. In order to counteract these deficits supplementary training is needed. The back squat (BS) is a valuable fundamental movement which trains strength and symmetry and is therefore possibly beneficial for dancers. However, due to aesthetic beliefs this type of training is often avoided by dancers although research has shown that it is possible with strength training to gain an increase in strength without altering aesthetics. The purpose of this cross-sectional study was to identify functional deficits in the BS pattern in relationship to the ROM in the hip. It was found that 74.5% of the participants demonstrated 5 or more functional deficits in the BS pattern, due potentially to a weak posterior chain, and that flexible ROM in the hip without necessary strength in and around this joint to aid symmetry and strength in the movement probably caused some functional deficits to be demonstrated. Moreover the results of the ROM measurements in the hip underline the physical individuality of each dancer, making a case not only for supplementary training for strength and symmetry, but that this should be tailored to individual needs.

Key words: Back Squat, Hip ROM, Strength, Imbalance, Supplementary Training

Introduction

Research has shown that dancers are not as fit as they need to be in order to accomplish the physical demands made on them and to avoid fatigue and injuries (Brinson &

Dick, 2006), (Koutedakis & Jamurtas, 2004), (Koutedakis, et al., 2007), (Allen & Wyon, 2008). From a neuromuscular and biomechanical perspective, fundamental movement patterns such running, jumping, throwing and squatting are highly significant and strengthening them will bring improved physical performance, mitigate injury risk, plus support independent living in later years (Myer & McGill, 2012). These fundamental movement patterns are present in many components of physical fitness; aerobic and anaerobic fitness, muscle strength and power, muscle flexibility and joint mobility (Koutedakis & Sharp, 1999, pp. 90-92). The physical demands placed on dancers make physiology and fitness equally important as skill development and "dancers must be experts in the aesthetic and technical side of the art, psychologically prepared to handle the stress of critical situations and be free from injury; most importantly they must be physically ' fit '" (Angioi, Metsios, Koutedakis, & Wyon, 2009, p. 475), (Koutedakis & Sharp, 2004, p. 714).

In the dance world it is still commonly believed the ballet class, not only for ballet dancers but also often for modern contemporary dancers, is the cornerstone of training, producing high athletic performance in strength, power, endurance and skill (Rafferty, 2010). While this is the case with skill, (Krasnow & Chatfield, 1996) and (Wyon, Redding, Abt, Head, & Sharp, 2004) the same cannot be said for aerobic strength and power (Wyon, Head, Sharp, & Redding, 2002) and muscular strength (Koutedakis, Stavropoulos-Kalinoglou, & Metsios, 2005). Much research, e.g. Allen and Wyon (2008) and Kumar (2001) has shown that dancers are often not as muscularly strong as they need to be in order to perform optimally and to avoid injuries when fatigued. A study from Koutedakis, Agrawal and Sharp, (1998) recorded that dancers do not demonstrate the same strength levels as other equivalent athletes. Furthermore, in a review of research on thigh injuries, Deleget (2010) reported that dancers had less thigh strength than athletes and non-dancers, plus dancers often demonstrate abductor-adductor and hamstring-quadriceps ratio imbalance. Hamilton, Hamilton, Marshall and Molnar (1992) observed an imbalance in the hip joint in the form of

restriction of the internal rotation in dancers whose training places great emphasis on the external rotation of the leg. Moreover, Rodriguez, Bolia, Philippon, Briggs, and Philippon (2019), found that a significant proportion of ballet dancers show signs of microinstability in the hip joints and stated that this may cause a predisposition to injury (2019) and Koutedakis and Sharp (1999) stated that it is necessary to consider all components of fitness but that dancers often emphasize flexibility but neglect strength and other conditioning elements. The evidence strongly suggests that supplementary training that addresses imbalances of strength and flexibility in combination should be included in the dancer´s schedule.

However, although muscular strength training and the training of fundamental movement patterns which can help to even-out imbalances are vital components of physical fitness, they are often avoided by dancers due to false beliefs, such as; that strength training will damage aesthetics and produce unsightly muscles (Twittchet, Koutedakis, & Wyon, 2009). Dancers are particularly wary about exercises that could potentially enlarge the thighs although research has shown that it is possible with strength training to gain an increase in strength without altering thigh aesthetics (Twitchett E. , Angioi, Koutedakis, & Wyon, 2011) & (Koutedakis & Sharp, 2004).

Unfortunately such beliefs lead to dancers failing to utilise traditional fundamental strength training methods from which they could profit vastly. The back squat (BS) is one such traditional strength training exercise and is a well-researched action used as a basis for a wide range of movements in sports, athletics, daily life and rehabilitation. Myer et al. (2012) suggested that the BS can be used not just as a fundamental strength and motor training exercise, but also as a screening tool to identify and correct functional deficits in athletes.

Anecdotal observation has shown that not only are dancers reluctant, mainly due to aesthetic beliefs, to undertake squats, but that many dancers show deficits in this movement. Deficits in the squat pattern are due to incorrect neuromuscular patterns, weakness, or strength and flexibility imbalances (Myer, et al.,2012). Research shows that dance training

alone does not produce adequate strength (Allen & Wyon, 2008) (Kumar, 2001) and that training that places emphasis on the outwards rotation of the hip possibly restricts internal range of movement (ROM) in the hip Hamilton et al. (2006), while Myer et.al (2012) state that (among other skills) flexibility and strength in the hip joint, both in internal and external rotation are needed to aid successful squats. Using the screening model from Myer et al. (2012), this study aims to explore how the passive external rotation and passive internal rotation in dancers´ hips impacts the pattern of the BS and to make a convincing case for squatting as a valuable strength and screening exercise for dancers.

It was hypothesised that not only does a lack of muscular strength in dancers cause deficits in the BS, but that also a manifestation of imbalance in the strength and flexibility of the muscle groups involved in the accomplishment of the internal and external rotation in the hips causes functional deficits to be detected.

Method

Participants. 51 male (N=7) and female (N= 44) healthy dance students, mean age 21± 2.4 years (range: 17 to 26 years) enrolled in full-time professional vocational education courses from two universities took part in this study. Written consent was obtained from both universities (Appendices A and B). The focus of both of the programmes was intensive engagement with contemporary dance. Classical ballet classes were given on a daily basis. Ethical clearance was given by the School Research Committee of the University of Wolverhampton. All participants signed an informed consent form (Appendix C) and filled out a pre-test health questionnaire (Appendix D).

Procedure. For this study, the proposed assessment model of functional deficits (FD) in the BS from Myer et al. (2012) was implemented. In order to maximise the consistency of the assessment, arm position, stance and verbal instruction was administered in a standardized form (2012, p. 6).

Firstly, participants were given written information (Appendix E) and verbally informed either as a group or individually, of the aims of the study and benefits of taking part in the study. Secondly the correct BS technique (holding a dowel over the shoulders) was explained. Thirdly, the participants were informed of how the rotation of the hip was to be measured and that they could, at any time, withdraw from the study. Finally, all questions concerning the study that arose before and during measurement were answered by the researcher. All participants´ data was handled confidentially; only the researcher had access to participants'´ name, contact and film data. This data was not shared with a third party. To further protect identity all participant names were exchanged for numbers.

Back Squat Data Collection. After ensuring that participants were warmed-up the standardised script for verbal instruction was read aloud to the participant:

> Please stand upright with feet shoulder width apart. Squat down until you believe that the top of your thighs are parallel to the ground, and then return to the initial starting position. Perform 5[1] continuous repetitions at a consistent, moderate pace, or until you are instructed to stop. Adapted from Myer et al. (2012, p. 8)

Following this the participant undertook 5 BS movements while holding a wooden dowel (3cm in diameter and 92cm long) across their shoulders. The BS movement was filmed simultaneously from the front and the side using Cannon Ixus 255H5 and Sony HDR-CX130 cameras. The cameras were placed 60-80 cm above ground level as in Myer et.al (2012) and 3.10 m and 3.76 m away from the participant. This was far enough away from the participant to be able to zoom in as needed, Myer et.al (2011) and dependent on the available space.

[1] 10 Squats were undertaken in the research from Myer et al. (2012)

Participants received verbal cueing in alignment with the dynamic screening tool from Myer et.al (2012) throughout the data recording.

Myer et al. (2012) divided the criteria for a successful BS into 3 domains; upper body, lower body and movement mechanics. FD for each of these domains were attributed to neuromuscular, strength or mobility paucities. Figure 1 shows the criteria for the BS.

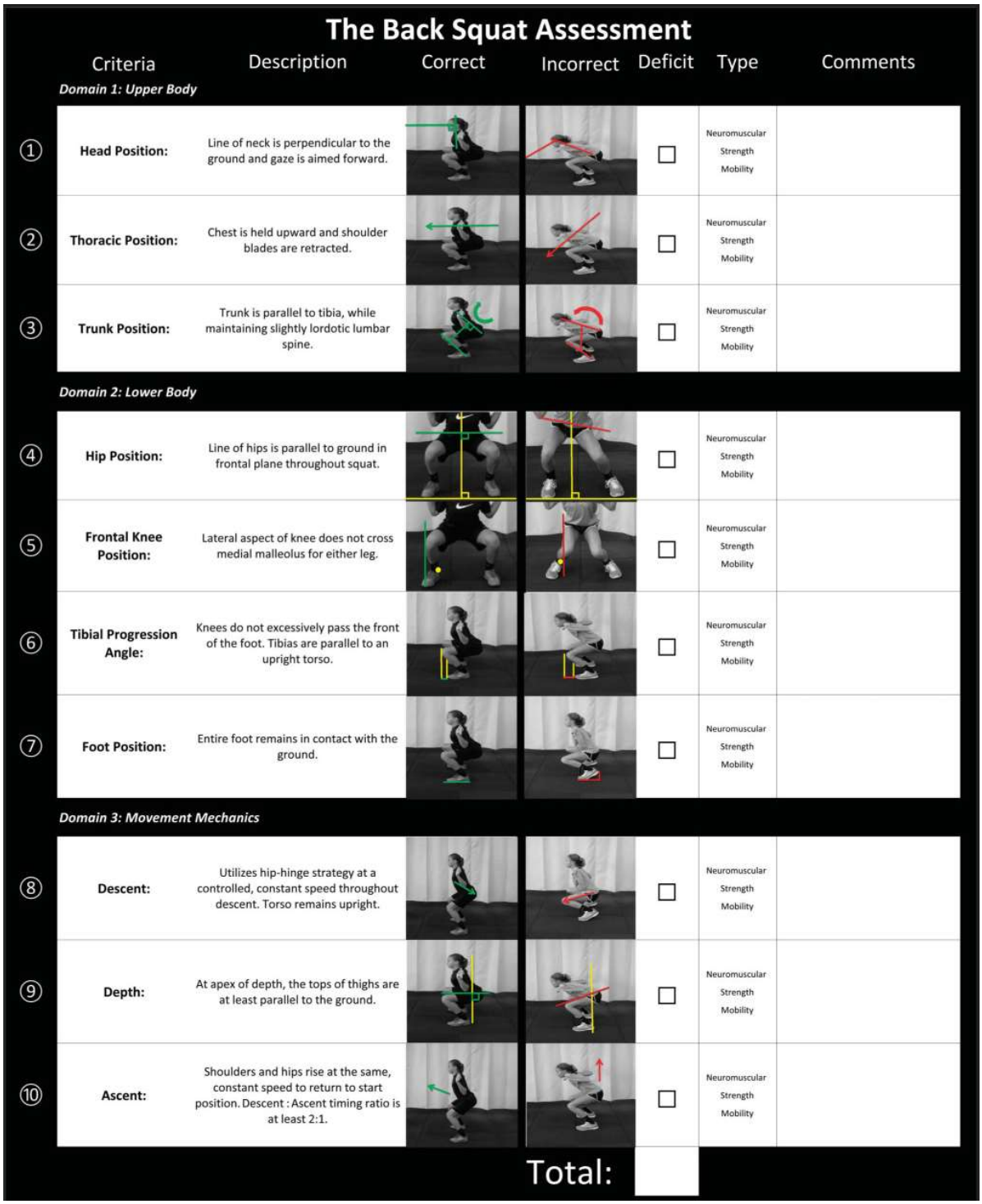

Figure 1, *Assessment of Back Squat functional deficits* (Myer & McGill, 2012, p. 7)

Measurement of rotation in the hip joint. The recommendations for measuring passive external and internal rotation from Hamilton et.al (2006) were followed; the participant lay prone, hips extended, with one leg flexed to 90° on a comfortable, flat surface. A measuring device (inclinometer) was attached with Velcro straps directly on to the joint line of the knee of the participant. In this study the inclinometer in an iPhone 6s was implemented and attached directly onto the joint line using the Velcro closure of a smartphone armband (cellularline Armband Spider 1654367). The researcher held and moved the leg on the side to be measured while placing the other hand on the gluteus maximus of the participant to ensure that the contra lateral pelvis did not move. Using the lower leg as a lever, the thigh of the measured leg was rotated by the researcher (inwards and outwards) while the knee remained flexed at a 90° angle. Internal and external passive hip rotation were measured separately on each leg and then combined to calculate the complete passive external rotation and complete passive internal rotation. ROM data was recorded in Excel.

Recordings of normal ROM measurements vary depending on the source. It was decided that data from Hamilton et al. (1992, p. 270) would be used as a guideline to help detect ROM abnormalities in the participant group. In that protocol, the mean right and left passive external rotation in the hip for female and male participants measured 52° and the mean passive internal rotation measured 29° for females and 22° for males. In comparison, the normal female and male population measured 40° for passive external rotation and the females 34° and the males 43° for passive internal rotation (p. 270).

Results

Two participants were wearing footwear which could have altered the squat pattern, plus two recordings due to incorrect camera usage during data collection were missing. Therefore, data from 4 participants of the 51 were eliminated, leaving a sample number of 47; male, N=7 and female, N= 40. The original number given to each participant was exchanged

in order to chronologically organise each group that emerged from the results. The results were calculated using Excel.

Hip Rotation. The individual measurements for passive internal and external hip rotation were highly varied and the female students showed a slightly higher mean passive external rotation than their male counterparts (see Appendix F). Of the sample population, 61.7 % N= 29 (4 male, 25 female) were measured with greater passive internal rotation and 36.2 %, N= 17 (3 male, 14 female) were measured as having a greater passive external rotation. Of the sample population 2.1 %, N=1, (female) was measured with equal complete passive rotation. The greatest difference in ROM measured when internal rotation was dominant, was 47°, when external rotation was dominant the greatest difference measured was 60°. When further dividing the sample into male or female with greater passive internal or external rotation it was found that males (N = 3) with greater passive external rotation accounted for 6.4% of the sample and had a mean passive internal rotation of 86° ± 11.6° and passive external rotation of 109.3° ± 18.9°, with an FD mean of 4.7. Males (N = 4) with greater passive internal rotation accounted for 8.5 % of the sample and had a mean passive internal rotation of 102.5° ± 4.7° and passive external rotation of 89.8° ± 10.8°, with an FD mean of 6.3. Females (N= 14) with greater passive external rotation accounted for 29.8% of the sample and had a mean passive internal rotation of 91.1° ± 12.2° and passive external rotation of 111.4° ± 12.7°, with an FD mean of 5.2. Females (N= 25) with greater internal rotation accounted for 53.2% of the sample and had a mean passive internal rotation of 113° ± 12.9° and passive external rotation of 89.7° ± 7.9° with an FD mean of 5.2. One female, accounting for 2.1% of the sample had equal passive internal and external rotations of 76° and demonstrated 5 FDs.

Back squat and functional deficits. Using the screening guidelines in Myer et al. (2012), filmed data was evaluated and recorded in a word document (see Appendix G). When FDs

were not clear (e.g. tibial progression) the movement analysis program Kinovea was implemented.

The overall mean number of FDs detected in the squat pattern was calculated at 5.3 ±1.86. The mean number of FDs and the standard deviation thereof for those with greater passive internal, passive external or passive equal rotation is depicted in Table 1.

Table 1, Mean and SD of FD in the squat pattern for GCPER, EQCPR & GCPIR

	GCPER [a]	*EQCPR* [b]	*GCPIR* [c]	
Mean FD	5.18	5	5.45	
SD FD	1.82	0	1.89	
Mean FD, GCPIR > GCPER				0.27

[a] Greater Combined Passive External Rotation, [b] Equal Combined Passive Rotation, [c] Greater Combined Passive Internal Rotation

The group with greater internal rotation was shown to have a greater mean FD than that of the group with greater external rotation. However, in a two sample t-Test assuming equal variances this was calculated at not being a significant difference since $P > 0.05$.

Hip rotation in relationship to functional deficits. For both groups; those with greater passive internal rotation and those with greater passive external rotation, incorrect head, neck and gaze positioning (FD1), incorrect positioning of the torso and loss of the lordotic curve (FD3), knee valgus (FD 5), and rolling ankles and/ or instable feet (FD 7) were the most often displayed FDs. Certain FDs from the screening model (Myer et al. (2012) were found more frequently in one group than in the other (Table 2). In those with greater internal rotation FD 6 (tibial translation angle faults) was shown in 31 % and FD 8, (descent faults) in 58.6 % of participants. The occurrence of FDs 6 and 8 in those with greater external rotation was 11.8 % and 47 % respectively. Those with greater external rotation showed deficits more often in

FDs 1, 2, 5, 9 and 10; incorrect head neck and gaze position (FD 1) dropped chest (FD 2), knee valgus (FD 5) lack of sufficient depth (FD 9) and suboptimal assent (FD 10).

Table 2, *Sum of specific FD for each group and the percentage of each group that demonstrated specific FD*

FD	GCPER [a]	CPER %	EQCPR [b]	EQCPR %	GCPIR [c]	GCPIR %
1	16	94.1	1	100	25	86.2
2	8	47.0	1	100	11	37.9
3	11	64.7		100	19	65.5
4	8	47			13	44.8
5	11	64.7			17	58.6
6	2	11.8			9	31
7	15	88.2			26	89.7
8	8	47	1	100	17	58.6
9	10	58.8			13	44.8
10	3	17.6			4	13.8

[a] Greater Combined Passive External Rotation, [b] Equal Combined Passive Rotation, [c] Greater Combined Passive Internal Rotation

Corresponding functional deficits compared with hip rotation. Participants with 100% FD shared scores and their differing measurements of passive internal and external rotations are shown in Table 3. No two participants shared 100% equal internal and external rotation measurements. Participant 47 who was measured with equal internal and external rotation did not however have equal measurements for the right and left sides and had an FD score of 5.

Table 3, *Participants (P) with 100% shared scores plus PIR, PER, CPIR and CPER measurements*

Participants	Right PIR[a]	Left PIR	CPIR[b]	Right PER[c]	Left PER	CPER[d]	FD	FD = N
Female GCPER							1,7,9	
8	53	48	101	53	50	103		3
Female GCPIR								
32	58	51	109	50	49	99		3
Female GCPER							1,4,5,7,9	
9	55	62	117	63	57	120		5
Female GCPIR								
38	59	65	124	46	53	99		5
Female GCPER							1,2,3,5,7	
11	38	43	81	57	48	105		5
Female GCPIR								
25	48	57	105	48	41	89		5
Female GCPER							1,3,5,7,9	
18	50	42	92	56	59	115		5
Female GCPIR								
47	39	37	76	36	40	76		5
Female GCPIR							1,3,4,5,7,9	
39	48	60	108	46	46	92		6
41	66	61	127	48	58	106		6
Female GCPER							1,2,3,4,5,7,8,9	
13	38	46	84	54	50	104		8
16	41	54	95	51	52	103		8
20	54	56	110	62	62	124		8

[a] Passive Internal Rotation, [b] Combined Passive Internal Rotation, [c] Passive External Rotation, [d] Combined Passive External Rotation

Discussion

This study aimed to explore how the passive external rotation and passive internal rotation in dancers´ hips impacts the pattern of the BS and to make a convincing case for squatting as a valuable strength and screening exercise for dancers. Although it was found that neither dominant external rotation nor dominant internal rotation played a greater part than the other in the quality of the squat pattern, the FDs that were observed most frequently in the dancers are (apart from FD 1), related to the strength and flexibility of the hip and thigh areas. FD 3 demonstrates lack of mobility of the hip and trunk flexors and possibly a restriction in the posterior fibres of the IT band that inserts into the gluteus maximus (Kushner, et al., 2015, p. 7). FD 5 demonstrates knee valgus and is linked to the flexibility and imbalance of strength in the hip. Knee valgus can be caused by increased hip adductor activation without adequate posterior chain control, a restricted ankle dorsi-flexion, and/ or decreased hip abductor and hip external rotation strength. (Myer & McGill, 2012, p. 15). FD 7, demonstrates instable feet and ankles and may be caused by knee valgus (Kushner, et al., 2015, p. 9) and in this case is then a result of strength and/ or flexibility deficits in the hip and thigh area.

The FDs detected while observing the BS could be correlated to the dancers` technique and susceptibility to injury. A lack of flexibility in the external rotation can cause the dancer to compensate and to force the turn-out which tips the pelvis forwards causing the knees to flex slightly which in turn weakens and tightens the hamstrings which then overloads the calf muscles leaving them vulnerable to injury and weakness (Howse & Hancock, 1988). In a study undertaken on contemporary dance students Jenkins, Wyon and Nevill (2013) identified that compensated and muscular values in the use of turn-out significantly increases the risk of injury.

Equally problematic is flexible external rotation/ turn-out without the necessary strength to maintain it over a period of time and during movement. According to Deighan

(2005), it has been suggested that "if the passive turnout is greater than the active turnout measurement, it is an indication that a dancer uses a forced turnout due to a muscular weakness or soft-tissue tightness." (p. 14). When a young student demonstrates a natural flexible external rotation, it is important that the teacher does not demand the use of this ROM without the dancer first having built the strength needed with which to maintain it. Sutton-Traina et al. (2015) state that "Turnout is a dynamic activity requiring strength and motor control to achieve and maintain end range positions" (p. 79). Flexibility without strength in the hip joint can cause instability resulting in knee valgus and in turn, instability in the feet and ankles leaving these joints susceptible to injury. Knee valgus and rolling ankles are the direct cause of many knee and foot injuries (Howse & Hancock, 1988). Further research investigating the occurrence of FDs in the BS in correlation to injury patterns in dance is needed in order to shed more light on the importance of functional movement for dancers.

Regardless of the dominance of the direction of the ROM in the hips, the detection of the FDs in the dancers taking part in this study supports the findings of earlier research that dancers lack muscular strength and that in order to counteract this, supplementary strength training is vital. In addition, training that concentrates on building and maintaining strength in the deep rotators[2] (Simmel, 2009, p. 97) plus posterior chain strength in balance with the adductor and abductor strength (Myer, et al., 2012), should be undertaken.

The BS requires the co-ordinated (and symmetrical) interaction of numerous muscle groups and strengthens prime movers necessary for explosive athletic movements, running, jumping and lifting and furthermore, it is suggested that squatting reflects lower limb movement patterns that are often required for success in explosive techniques that expose the joints of the lower extremities to high loads (Myer, et al., 2012). Research has found that pre-professional dancers (age 18.9 years) land with a ground reaction force of 4.5 times their body weight when performing a *saut de chat/ grand jeté* (Kulig, Fietzer, & Popovich, 2011) which

[2] Piriformis, gemellus superior and inferior, quadratus femoris and the obturatorius internus and externus.

highlights the amount of power and resistance that needs to be trained for the grand allegro. Myer et al. (2012) state how developing proper squat mechanics before using external resistance will minimise compensatory strategies and protect against injury. This makes the BS a vital prerequisite to weight bearing movements (p. 24) such as landing from a jump or lifting a partner. The stress that partner work puts on the body not only affects male classical ballet dancers but also modern and contemporary dancers of both genders.

The training of the cohort examined in this study included a daily classical ballet class with greater emphasis placed on contemporary dance where the dancers work mainly in parallel and turn-out is not a priority. This and the former training of these dancers may have been reasons as to why internal rotation was dominant and much greater than that of the professional ballet dancers and greater than that of the normal population. Although some of the participants had a background of intense ballet training during early adolescence, the majority of the dancers were late starters, some with very little experience of the turn-out technique that ballet demands.

Researchers theorise that training the turn-out for more than six hours a week at 11–14 years of age is associated with more retro-torsion of the femur which is associated with greater external ROM at the hip joint and is commonly found in ballet dancers (Hamilton, et al., 2006). Hamilton, Hamilton, Marshall and Molnar (1992) and Reid, Burnham, Saboe, and Kushner, (1987) found that professional ballet dancers have, in comparison to controls, greater external and restricted internal rotation but whether this resulted from alterations in femoral torsion in the growing bone or from anterior capsular stretch, is not known (Hamilton, et al., 1992). A longitudinal study examining vocational ballet students is needed in order to gain insight into the relationship between the BS pattern and restricted internal rotation caused by repeated, emphasised turn-out training.

The findings of this study underline the variability of the individual. Although dancers did have corresponding FD scores and occasionally similar ROM in the hip, no two dancers

were found to have identical measurements for ROM. Consequently, wherever possible, supplementary training should be tailored to meet individual needs (Koutedakis & Sharp, 1999, p. 158). Brinson and Dick state in *Fit to Dance*, “Class is by no means adequate fitness training, because the workload is not specific enough to train the different fitness parameters, nor is it graduated, nor tailored to individual needs.” (2006, p. 122).

Making dancers aware that they cannot gain the required amount of strength for dancing through dance alone and allowing time within their schedule to complete individually tailored supplementary training should be a priority for educational institutions. Furthermore, when screening dancers for further education programmes, not just skill, artistry and body aesthetics, but also basic fundamental movements such as the BS need to be observed. In this way, the dancer and the institution could be better informed about flexibility, strength, weakness and possible incorrect neuromuscular patterns and imbalances, so that constructive training plans can be drawn-up thus helping injuries to be avoided and the dancer`s potential to be optimally developed.

A limitation of this study was the absence of a professional measuring device such as a Goniometer or a Bubble Inclinometer. However, intermittent tests, e.g. when a dancer specifically asked for the measurement of ROM to be repeated, showed no unexplainable radical changes or inconsistency.

Conclusion

Results showed that maybe not only does a lack of strength in the dancer cause deficits in the BS, but that also a manifestation of imbalance in the strength and flexibility of the muscle groups involved in the accomplishment of the internal and external rotation in the hips causes functional deficits to be detected. These findings support earlier research which points to strength deficits in dancers, and also support the argument for squatting as a valuable strength and screening exercise for dancers.

In this sample population the main findings revealed that a weakness in the fundamental BS pattern was prevalent and that neither internal nor external rotation had a greater impact on the BS pattern. 74.5% of the dancers demonstrated 5 or more FDs. The lowest FD score attained was 1 (N=1), the highest, 10 (N=1). A deficit free squat pattern was not observed.

References

Allen, N., & Wyon, M. (2008). Dance medicine: artist or athlete? *Sportex Medicine*(35), 6-9.

Angioi, M., Metsios, G., Koutedakis, Y., & Wyon, M. (2009). Fitness in contemporary dance: a systematic review. *International Journal of Sports Medicine, 30*, 475 – 484.

Baker Jenkins, J., Wyon, M., & Nevill, A. (2013). Can turnout measurements be used to predict physiotherapist-reported injury rates in dancers? *Medical Problems of Performing Artists, 28*(4), 230-235.

Brinson, P., & Dick, F. (2006). *Fit to dance?* London: Calouste Gulbenkian Foundation.

Deighan, M. (2005). Flexibility in dance. *Journal of Dance Medicine & Science, 9*(1), 13-17.

Deleget, A. (2010). Overview of thigh injuries in dance. *Journal of Dance Medicine & Science, 14*(3), 97-102.

Hamilton, D., Aronsen, P., Løken, J. H., Berg, I. M., Skotheim, R., Hopper, D., . . . Briffa, N. (2006). Dance training intensity at 11-14 years is associated with femoral torsion in classical ballet dancers. *British Journal of Sports Medicine, 40*(4), 299-303.

Hamilton, W., Hamilton, L., Marshall, P., & Molnar, M. (1992). A profile of the musculoskeletal characteristics of elite professional ballet dancers. *American Journal of Sports Medicine, 20*(3), 267- 273.

Howse, J., & Hancock, S. (1988). *Dance Technique and Injury Prevention.* London: A & C Black.

Koutedakis, Y., & Jamurtas, A. (2004). The dancer as a performing athlete. *Journal of Sports Medicine, 34*(10), 651-661.

Koutedakis, Y., & Sharp, N. (1999). *The Fit and Healthy Dancer* (1st ed.). Chichester: Wiley.

Koutedakis, Y., & Sharp, N. (1999). *The Fit and Healthy Dancer* (1st ed.). Chichester: Wiley.

Koutedakis, Y., & Sharp, N. (2004). Thigh muscles strength training, dance exercise, dynamometry, and anthropometry in professional ballerinas. *The Journal of Strength & Conditioning Research, 18*(4), 714-718.

Koutedakis, Y., Agrawal, A., & Sharp, N. (1998). Isokinetic characteristics of knee flexors and extensors in male dancers, olympic oarsmen, olympic bobsleighers, and non-athletes. *Journal of Dance Medicine & Science, 2*(2), 63-67.

Koutedakis, Y., Hukam, H., Metsios, G., Nevill, A., Giakas, G., Jamurtas, A., & Myszkewycz, L. (2007). The effects of three months of aerobic and strength training on selected performance and fitness-related parameters in modern dance students. *Journal of Strength and Conditioning Research, 21*(3), 808–812 .

Koutedakis, Y., Stavropoulos-Kalinoglou, A., & Metsios, G. (2005). The significance of muscular strength in dance. *Journal of Dance Medicine & Science, 9*(1).

Krasnow, D., & Chatfield, S. (1996). Dance science and the dance technique class. *Impulse, 4*, 162-172.

Kulig, K., Fietzer, A., & Popovich, J. (2011). Ground reaction forces and knee mechanics in the weight acceptance phase of a dance leap take-off and landing. *Journal of Sports Sciences, 29*(2), 125–131. doi:org/10.1080/02640414.2010.534807

Kumar, S. (2001). Theories of musculoskeletal injury causation. *Ergonomics, 44*(1), 17-47.

Kushner, A. M., Brent, J. L., Schoenfeld, B. J., Hugentobler, J., Lloyd, R. S., Vermeil, A., . . . Myer, G. D. (2015). The backsquat part 2: targeted training techniques to correct functional deficits and technical factors that limit performance. *The Journal of Strength & Conditioning Research, 37*(2), 13–60. doi:10.1519/SSC.0000000000000130

Myer, G. K., & McGill, S. (2012). The back squat: a proposed assessment of functional deficits and technical factors that limit performance. *Strength and Conditioning Journal, 36*(6), 4-27.

Myer, G., Ford, K. R., & Hewett, T. E. (2011). New method to identify athletes at high risk of ACL injury using clinic-based measurements and freeware computer analysis. *British Journal of Sports Medicine, 45*. doi:238–244. doi:10.1136/bjsm.2010.0728

Rafferty, S. (2010). Considerations for integrating fitness into dance training. *Journal of Dance Medicine & Science, 14*(2), 45-49.

Reid, D., Burnham, R. S., Saboe, L. A., & Kushner, S. F. (1987). Lower extremity flexibility patterns in classical ballet dancers and their correlation to lateral hip and knee injuries. *American Journal of Sports Medicine, 15*(4), 347-352.

Rodriguez, M., Bolia, I. K., Philippon, M. D., Briggs, K. K., & Philippon, M. J. (2019). Hip screening of a professional ballet company using ultrasound-assisted physical examination diagnosing the at-risk hip. *Journal of Dance Medicine & Science, 23*(2), 51-57.

Simmel, L. (2009). *Tanzmedizin in der Praxis* (1 ed.). Leipzig: Henschel Verlag.

Sutton-Traina, K., Armour Smith, J., Jarvis, D., Lee, S., & Kulig, K. (2015). Exploring active and passive contributors to turnout in dancers and non-dancers. *Medical Problems of Performing Artists, 30*(2), 78-83. doi:10.21091/mppa.2015.2013

Twitchett, E., Angioi, M., Koutedakis, Y., & Wyon, M. (2011). Do Increases in Selected Fitness Parameters Affect the Aesthetic Aspects of Classical Ballet Performance? *Medical Problems of Performing Artists, 26*(1), 35–38.

Twittchet, E., Koutedakis, Y., & Wyon, M. (2009). Physiological fitness and professional classical ballet performance: a brief review. *Journal of Strength and Conditioning Research, 23*(9), 2732-2740.

Wyon, M., Head, A., Sharp, C., & Redding, E. (2002). The cardiorespiratory responses to modern dance classes: differences between university, graduate, and professional classes. *Journal of Dance Medicine & Science, 6*(2), 41-45.

Wyon, M., Redding, E., Abt, G., Head, A., & Sharp, N. (2004). Oxygen uptake during modern dance class, rehearsal, and performance. *The Journal of Strength and Conditioning Research*, 646-649. doi:10.1519/13082.1