Balance in theatrical dance performance: a systematic review

Balance in theatrical dance performance: A systematic review

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Abstract

Purpose: Due to movement complexity and the use of inter-disciplinary styles, all theatrical dance genres require dancers to have excellent balance skills to meet the ever increasing choreographic demands. The aim of this systematic review was to evaluate the evidence for the relationship between balance and dance performance, including balance testing, balance training and balance performance. The key focus was on balance and theatrical styles of dance, involving adult participants who were either in full-time dance training or professional dancers. **Methods:** The electronic databases MEDLINE, Cumulative Index to Nursing & Allied Health (CINAHL), PubMed, SPORTDiscus, Cochrane, ScienceDirect, and Google Scholar were searched using MeSH terms “postural balance”, “balance, postural”, “musculoskeletal equilibrium” and “postural equilibrium” used in combination with “dance” between 1980-2016. PRISMA recommendations were applied in modifications to the search terms. **Results:** The initial search revealed 1,140 published articles. After applying inclusion and exclusion criteria, 47 articles were judged to be relevant for further assessment using the GRADE system. Results revealed only one RCT study; the remaining ones were experimental without randomisation or pre-experimental, thus achieving low scores. The total of 39 articles focused on balance ability, including postural sway and control, five were related to multi-joint coordination and three articles investigated laterality and balance. Female ballet dancers were the most studied population while a wide range of measurement tools and balance tasks were employed. **Conclusion:** It was concluded that the available material on balance and dance performance is of rather low quality. There is a need for more RCTs and intervention balance studies.

Introduction

Dance as an aesthetic art form, can be defined as theatrical dance. This type of dance demonstrates original choreography, a high level of skill, and is created for an audience. Dance is a challenging activity[1] where appropriate physical fitness[2-4] and aesthetic competence[5] are necessary for optimal performance[1,6,7], and for reducing incidents of burnout [8] and musculoskeletal injuries[9,10]. Dance is also characterised by high levels of balance which is regarded as a fundamental component of dancers' training[11] and their professional career[12,13]. Dancers are viewed as the balance experts who are able to demonstrate difficult balancing activities[14,15] possibly due to faster postural responses[16,17] and enhanced proprioceptive sensitivity[18-20]. In light of this, balance needs to be considered in relation to a dancer's individual needs in a training context[21].

It has been found that dance interventions have positive effects on balance in older adults[22-25], children[26,27] and in clinical populations[28] whilst exercise interventions can improve balance indicators in injured dancers[15,29-31]. The contribution of sensory inputs on balance has also been studied on dancers[14,16-20,32-37], including the effects of balance laterality[38,39]. Furthermore, while some conflicting results have emerged comparing balance ability between dancers and athletes[17,35,40], dancers were found to have greater multi-joint coordination in balance activities than untrained participants[41,42]. However, despite their acknowledged balance expertise, dancers have demonstrated less ability in balance skills than non-dancers using basic tests[17,20,43,44], although in more complex sensory challenged conditions, dancers have been shown to have superior abilities[45].

A review by Costa et al[46], examined static and dynamic balance in ballet dancers but, to our knowledge, no systematic reviews exist on the relationship between balance and dance performance. Therefore, the aim of this systematic review was to investigate the current state of experimental evidence on the relationship between balance and dance performance, including balance testing, balance training, and balance performance. The aim of the literature search was to identify all relevant literature on balance and theatrical styles of dance, involving adult participants who were either in full-time dance training or professional dancers.

Methodology

Literature search

The reference sources used were the electronic databases MEDLINE, Cumulative Index to Nursing & Allied Health (CINAHL), PubMed, SPORTDiscus, Cochrane, ScienceDirect, and Google Scholar to find publications from January 1980-October 2016, with no language restrictions. The Medical Subject Heading (MeSH) terms “postural balance”, “balance, postural”, “musculoskeletal equilibrium”, “postural equilibrium” and “dance” or “dancers” were used. Modifications were made to this search as known key texts in the research area were not included in the results using MeSH terms, and this modification was in line with PRISMA statement recommendations[47]. A subsequent search used the terms “balance”, “postural stability”, and “postural control” combined with “dance” using all the aforementioned databases.

A first-stage screening of titles and abstracts was conducted based on balance testing, balance training, and dance; relevant full articles were retrieved for the second-stage screening. Articles were eliminated using set inclusion and exclusion criteria (Figure 1). A second researcher peer reviewed all papers with particular reference to the inclusion and exclusion criteria. The following outlets were hand searched to ensure that all relevant articles were included: *Journal of Dance Medicine & Science* and *Medical Problems of Performing Artists*. The reference list of the only known literature review on balance in dancers[46] also was searched to ensure that no relevant papers were omitted.

Inclusion and exclusion criteria

Articles were included if they were experimental, referred to theatrical dance forms, involved professional dancers and/or dance students in vocational and university training, and examined balance. Articles were excluded if they were related to recreational dance, competition dance, involved participants aged younger than 17 and/or older than 45 years old. These age groups are more likely to be involved in recreational dance, and mostly fall outside the age range for professional theatrical dance. Editorials, reviews, abstracts, conference proceedings, theses, bulletins and newsletters were also excluded. Eligibility assessment was conducted in an unblinded standardised manner by two researchers; any disagreements were resolved by consensus based on PRISMA guidelines[47].

Quality appraisal

During the first screening, articles were appraised by title and abstract, to be deemed as probably relevant, unknown relevance or irrelevant. Articles that were categorised as probably relevant or of unknown relevance were subsequently obtained as full-texts. In the second screening, these texts were examined and included or excluded according to their relevance to the current review aims. All included articles met the following criteria: clearly stated aims, objectives, or hypothesis; clear description of participants with inclusion and exclusion criteria; appropriate, defined methodology, or a cohesive argument for using the methodology with reference to previously published work, or a pilot study; appropriate choice of statistical analysis with probability values; clear discussion of the results with reference to the original aims of the study; limitations of the study noted.

(Insert Fig 1 flow diagram)

In order to refine the process for the current review, the Grading of Recommendations Assessment, Development, and Evaluation (GRADE)[48,49] was applied as it provides a system for rating the quality of the evidence and grading the strength of recommendations presented in any studies under review. GRADE's approach to rating quality of evidence begins with the study design and then addresses five reasons to possibly rate the study lower and three reasons to possibly rate the study higher[50]. Randomised trials initially start the rating at a high level with observational studies starting at a low level. The five reasons for lowering the rating are risk of bias, inconsistency, indirectness, imprecision, and publication bias. The three reasons for raising the rating are if the study is deemed to have a large effect, a dose response, or all plausible residual confounding[50].

Results

The initial search revealed 1,140 articles. From those articles, 494 were duplicates and removed. Subsequently, 501 unrelated articles, 57 age-related articles and 41 health-related articles were also removed. Only 47 articles were judged to be relevant but none of them directly examined balance and performance. Thirty-nine articles relating to balance ability, including postural sway and control are presented in Table 1. Five articles relating to multi-joint coordination[41,42,51-53] are presented in Table 2. Three articles primarily investigating laterality and balance[38,39,54] are presented in Table 3.

Of the 47 relevant papers, only one included a random controlled trial (RCT)[31] and achieved a high GRADE score. This study was also the only one to include an intervention. The remaining studies were experimental without randomisation or pre-experimental and thus rated as a low score under GRADE recommendations. Small sample sizes were common, and imprecision on participants' gender[41,45,54,55] and age SD[14,35,56] further weakened the evidence[57,58]. The inclusion criteria were fairly limited and often just compromised of the number of years of training and ability level. Although 19 papers used the term "randomised" in their study design this related to the order of test conditions, legs, sequences, and testers. A set order of tests was common and in general, no reason was given for this, although Golomer and colleagues[59] stated an aim of reducing fatigue. Despite these limitations, studies demonstrated probability values of $p<0.05$ and a clear discussion of the results. Overall, the 47 articles demonstrated a breadth of participants, measuring tools, and research topics in their studies which reflects the current early stages of research in balance and dance.

Participants

Of the 47 papers, 27 articles included ballet dancers[13,14,16,17,19,20,33,34-36,38-42,54,55,59-68] , eight contemporary/modern dancers[30,40,44,68-72], one included Thai dancers[37], six included other expert athletes in an additional test group[17,18,35,38,40,41], 17 involved untrained participants (controls), and 13 comprised of dancers whose genre expertise was unspecified. Of the selected papers, 39 examined female participants, 19 males while four papers did not specify the gender of participants.

(Insert Table 1)

Testing procedures

Overall, the selected studies demonstrated a variety of testing procedures (Tables 1-3): 24 used force plates as the principal apparatus for testing balance[14,15,17,20,34-37,39,53-56,60,63-70,73,74], 10 studies employed motion capture analysis[41,52-54,59,61,62,64-66], seven studies used the stabilometer, sometimes referred to as a “seesaw”[16,18,19,33,38,75], placed on a force plate[36], five studies utilised a pressure mat[13,30,31,40,71], four studies included the SEBT or modified versions: SEBT[31,44,76], the modified SEBT[76], the Y-balance (SEBT components)[72]. Other assessment tools included the Balance Error Scoring System (BESS)[44], the modified Bass Test of Dynamic Balance (BASS)[44], a goniometer and computer generated visual target[42], a Rod and Frame Test (RFT)[16], a Biodex System[77], a Foam and Dome Test[45], and an observed timed-measure[51].

Whilst most studies employed quite basic balance tasks, a number of tests used dance-specific, complex balance tasks. Turns were regarded as a challenging balance activity[78] and seven studies tested balance using pirouettes[55,59,61,62,65,66,68]. These studies covered a range of research questions including control strategies on two types of turn[68], leg stability and trunk strategies for ballet dancers and untrained participants[62], and the relationship between visual information and postural control including gaze fixation in turns[61] . Four studies used balance tasks en pointe (balancing on the tips of the toes in reinforced pointe shoes)[14,15,54,60], four included a complex balance position namely: arabesque[52,73], attitudes[13], and retiré[64] and one study included beaten jumps (legs cross in mid-air)[39].

Vision conditions

The total of 20 papers adopted specific vision conditions in their testing. Visual input was viewed as important for postural control and dancers demonstrated better balance ability in eyes open conditions[14,63]. Other studies[17,20] found no differences between dancers and controls in eyes-open conditions. In closed eyes conditions, dancers have found it harder to maintain postural control than non-dancers [14,17], or had less visual field-dependency than non-dancers[16].

(Insert Table 2)

Multi-joint coordination

Six articles focused on multi-joint coordination in relation to balance ability (Table 2). Dancers were more successful in reproducing the orientation and shape of an ellipse than novices[41]. Comparing dancers to non-dancers, Kiefer et al,[42] found that expertise did not seem to play a role in adoption of coordination patterns. Schmitt et al,[51] found that ballet training alone does not lead to improvements in ankle joint position or improved measures of balance. Differences were found in postural pelvic control and intra- and inter-limb coordination[52], and the less experienced group showed more variability in both dynamic and static postural control than the more advanced students and professional dancers. Jarvis et al,[53] reported that dancers had lower intersegmental coordination variability than non-dancers for LE sagittal, frontal, transverse plane couplings, and sagittal plane trunk couplings.

(Insert Table 3)

Laterality

Three articles focused on laterality and balance (Table 3), two based on testing solely dancers[39,54], whilst a study by Guillou et al,[38] assessing dancers, acrobats and soccer players, found that soccer players' asymmetrical equilibrium training led to a sensory organisation of their left support leg. Dance training is regarded as symmetrically based, and yet dancers often perceive a preferred "stronger" leg. Examining the relationship between postural stability and self-reported leg preferences, Mertz and Docherty[39] found no difference between the preferred leg and the non-preferred leg and the perceived heightened balance ability on one leg did not manifest itself in actual heightened balance ability in two-legged stance or one-legged stance. Lin and colleagues[54] found that the dominant side had a greater moment range than the non-dominant range, and proposed that the dominant side was the primary controller of balance in a dance movement. There were variations in the identification of the dominant leg. Two studies identified the dominant leg as the preferred leg in a dance-specific movement[39,54] which supports the complexity of lateral bias in dance such as ballet[79], whereas Guillou and colleagues[38] were similar to other studies in the review[64,73] identifying the dominant leg as the preferred leg kicking an object, although this is not a dance-specific skill[79] .

Discussion

The aim of this systematic review was to evaluate the evidence for the relationship between balance and dance performance, including balance testing, balance training and performance. According to our knowledge, no such systematic review has been previously conducted. Although there were a wide variety of studies investigating balance in dance, no studies examined balance and dance performance.

By applying GRADE recommendations[48], only one study was detected as having a RCT design[31]. This study was also the only one incorporating an intervention out of the 47 chosen articles. The remaining 46 studies demonstrated low scores and lacked precision in their methodology[57,58]. The limited number of RCTs indicates the current low level of research in dance; the latter has also been confirmed by others[80]. In addition, a number of studies were pre-experimental with only one group and/or no controls and these factors reflect poor methodology and an increased risk of bias[47,50]. The wide range of study designs across 47 articles demonstrates a lack of replication in this field.

Task difficulty

We found a variation of balance tasks employed by different research groups. Some of the standing balance tasks were found to be easy to maintain by dancers[51,67], whereas Hugel and colleagues[14] found that not all their dancers could perform the set tasks on pointe. The eyes open (EO) standing balance tasks on stable floor conditions in tests may create a biased effect as they generate little demand on balance abilities of dancers. In studies with complex dance-specific balance tasks, researchers need to be rigorous in gaining knowledge of the dancers' abilities before the start of the testing process so that the risk of bias is minimised. In general, given that fitness is part of the human fitness continuum[21] and that fitness affects aesthetic competence in dance[2] it becomes clear that dancers should incorporate supplementary training in their schedules as previously suggested[3,81].

Vision and stability conditions

Some dancers found vision and stability conditions increased the level of task difficulty[17,20] although the results were variable with some dancers showing poor balance in the least challenging tasks[37]. A shift from visual information to greater dependence on somatosensory information in dance training has been suggested[33], and this is supported by a later study which found that dancers were less stable when somatosensory information was made unreliable[20]. Dancers often train in front of a mirror and have spatial references in rehearsals and on stage and thus, struggle when those references are unavailable[14,19,33,35].

It has been suggested that dancers need to rely more on proprioception on stage as the stage lights are dazzling and nothing can be seen in the auditorium[19]. Tests on proprioception found that dancers relied on a greater proprioceptive input than nondancers, particularly when tested at a higher frequency band (2-20Hz) on a stabilometer which has been shown to indicate the contribution of proprioception to postural control[33]. Age and physiological maturity was suggested as a factor when assessing vision and equilibrium in a number of articles by Golomer and colleagues[18,19] who noted that 18 years old male students were more vision dependent than their female counterparts, due to a temporary deficiency in the trunk proprioceptive regulation caused by their growth acceleration. The different test protocols may complicate data evaluation, such as those from vision studies[14].

Dance-specific balance tasks

There were a variety of research outputs using complex dance-specific balance tasks. For example, Lin et al,[65] found that experienced dancers utilised translation strategies, whilst Hopper et al,[55] noted that dancers had better balance after turns than non-dancers. Further replication of the studies using dance-specific tasks, and the inclusion of interventions and RCTs would strengthen the data. Small sample sizes in dance-specific studies constituted a further limitation.

Adjustments in balance

Studies investigating multi-joint coordination reported less variability in intersegmental coordination[53] and ankle-hip coordination[42] in dancers with the exception of a jump prelanding stage[53]. Superior control may be indicated by less variability in the trunk and adjustments in balance[51-53]. Some studies on laterality reported that leg preference did not affect balance in jump landings[39] or unipedal stance[38] which concurs with others[81].

A number of studies examined in this review compared balance abilities between dancers and athletes. Different dynamic patterns were found in dancers compared to track athletes[35], whilst dancers demonstrated better balance than soccer players in certain tests including a greater ability to gain centre after perturbation[40]. In eyes open tests, judokas and dancers performed better than controls, but only judokas were able to maintain a better balance than controls in all the tests[17]. Different training strategies, physical and artistic demands, as well as different testing conditions may have affected the results.

Foot and shoe conditions

We also found that the studies used herein adopted a range of foot and shoe conditions in their protocols, such as barefoot[40], ballet shoes[15], a range of barefoot/shoe conditions[13,56] , and two studies used athletic shoes[73] and jazz sneakers[74] . These latter studies used time to stabilisation (TTS) protocols which test dynamic stability. To date, there is a paucity of published articles on TTS tests and dancers. This field merits further research in order to investigate TTS as a relevant test for dancers' balance ability, as it measures functional balance which is relevant to the dynamic demands of dance[82] .

Previous injury

Some studies compared balance to injury or joint instability. Clark and Redding[30] found a significant link between previous lower limb injury and postural sway concurring with previous studies, suggesting their balance tasks are a reliable method for identifying proprioceptive deficits from injuries. Lin et al,[15] noted that injured dancers may have inferior postural stability than non-dancers. The comparison of balance abilities between dancers and other groups has resulted in mixed findings, and as already noted, further replication of studies would increase the strength of evidence in this area.

Balance training and balance tests

Few alternative training protocols have been introduced to improve dancers' balance[31]. Therefore this field remains relatively under-researched and merits further scientific attention due to the importance of balance ability in dance. Researchers need to include detailed methodologies of the interventions in RCTs so that replication is possible. To our knowledge, only one other study has designed a balance intervention[80]; however, given that used volunteers were of a younger age group, this study was not included in the review.

The validity and reliability of balance tests for dancers remains a largely un-researched area. Modifications to the Star Excursion Balance Test have been investigated by only two studies with the aim to examine its potential use as a dance-specific balance screening tool[76,84]. Balance research using dance-specific pirouettes has been undertaken[55,62,65,66,68,78] but its validity as a balance tool is still under debate due to the variety of test conditions, and small sample sizes. The variation in balance complexity may be related to the difference in results in the literature[20], with a two-legged stance[20] being easier to maintain than a one-legged stance[45] or a balance position on a stabilometer[19]. Balance testing protocols need further scrutiny, as noted by Schmit et al,[35] when evaluating the methods of a study [45], which produced conflicting results.

Although the force platform was the preferred testing apparatus, a number of studies used balance field tests, which did not rely on dedicated equipment, but produced conflicting findings. Studies using the SEBT as a measuring tool noted that some of the reach distance positions might be redundant[31,44,76],when modifications made to the SEBT resulted in non-significant disturbances to dancers' gaze[76]. The study by Ambegaonkar and colleagues[44] is the first to compare balance and non-dancers using the BESS, SEBT and BASS; the authors found that dancers had better balance than non-dancers in some but not all conditions. From the outcomes of the studies in this review, there does not appear to be one type of measuring tool or equipment which presents itself as providing the best evidence.

Strengths and limitations

The present findings constitute a positive contribution to the existing body of knowledge as no such systematic review has been previously conducted. Another strength of this work is the detailed description of the search methodology. Medical Subject Heading (MeSH) terms were used in line with PRISMA statement recommendations[47]. Articles have been rated according to GRADE guidelines[48] with recommendations for use for researchers new to GRADE assessments[49]. There were no language restrictions.

It is reasonable to assume that the present results may have been influenced by methodological limitations. The search terms used to identify relevant published material might not be entirely representative of the studied field, whilst the lack of detail in their methodology, small sample sizes, and the lack of limitations in a number of the selected studies might have caused a degree of bias in the current analyses as previously indicated[48,50]. Age and maturation may be factors in vision and balance testing[18,19] , however, the inclusion criteria was restricted to adults only.

Conclusion

The limitations of the existing body of research on balance and dance performance have been exposed. Clear research questions, consideration of bias, clear inclusion and exclusion criteria and reporting in accordance to current scientific standards are recommended in the planning of future research studies. Further RCT research studies in the field of balance and dance may increase the strength of available data and the presentation of evidence. In addition, further replication of balance studies and development of intervention studies might identify balance deficits and training needs for dancers. As no studies examined the relationship between balance ability and dance performance thus far, this area merits further consideration.

The literature on balance and dance performance revealed mixed findings. Reported effects on dancers' balance included task difficulty, and changes in vision conditions and somatosensory information. Balance strategies were employed by dancers in some conditions, however in other conditions, superior control was exhibited by dancers with less variability in the trunk and ankle. Based on this evidence, further research in balance training might suggest ways to improve postural control. In terms of assessing balance, no assessment tool demonstrated itself as providing best evidence. Given the importance of balance ability for dancers, further research studies meeting current scientific standards in balance testing would be beneficial, and may enhance training programmes, optimal performance, and help to reduce the risk of injury.

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Fig 1. Flow chart

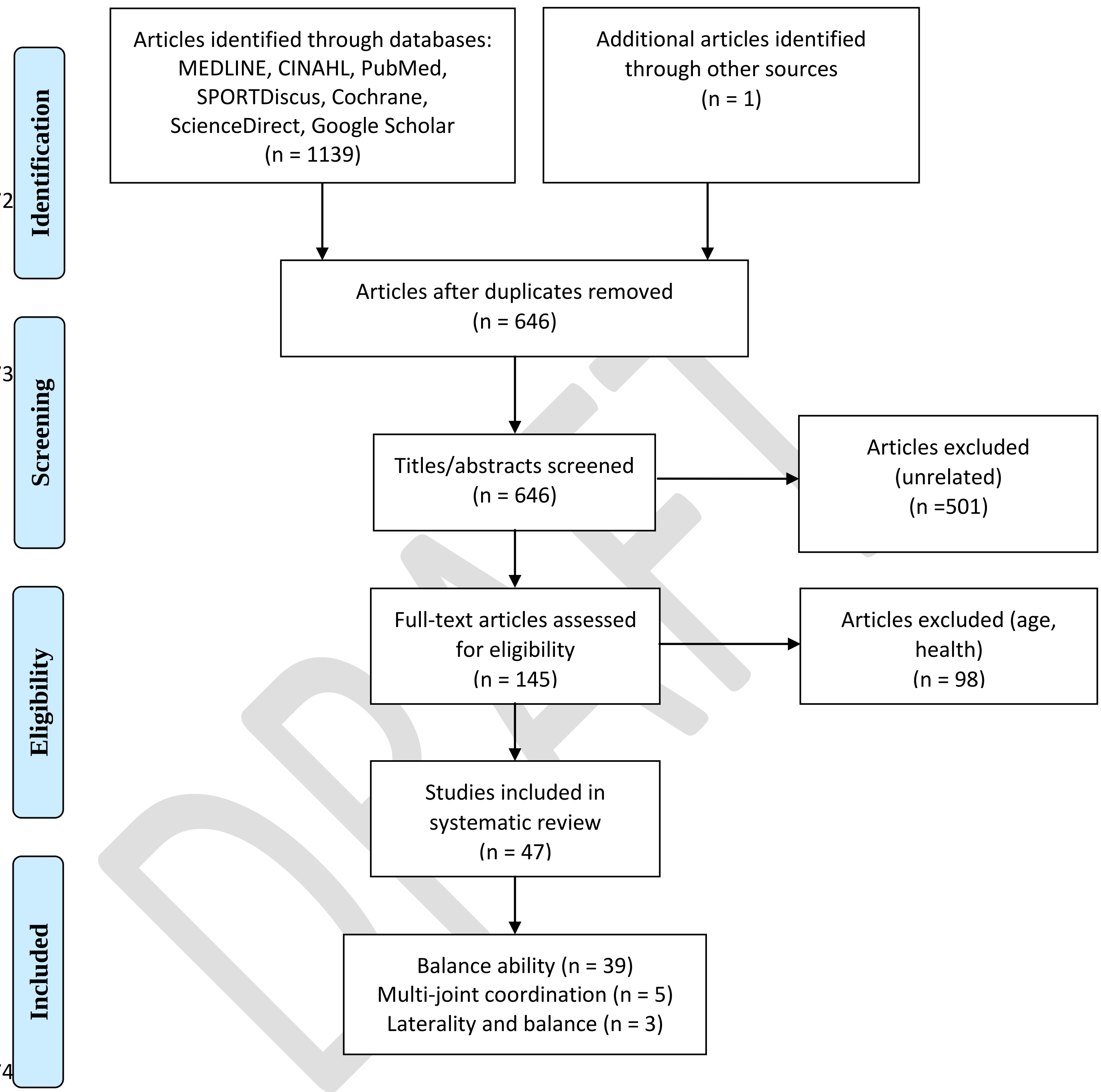

Fig. 1 Systematic review flow chart

A systematic review on balance and dance performance was conducted and after applying exclusion and inclusion criteria, 47 articles were selected for review. Three key areas across the 47 articles were revealed: balance ability, multi-joint coordination, and laterality and balance. Articles were then scored according to the GRADE system.

Table 1. Studies primarily investigating balance ability

Study	Study design	Participants	Method	Outcome	GRADE
Crotts *et al*, (1996)[45]	Set order of tests following protocol of earlier clinical test	Dancers from Dance Dept, Temple University, USA n=15 (No gender stated) 27±18.3 yrs Non-dancers from PT Dept, Temple University n=15 (no gender stated) 27±16.4yrs	5 x 30second (s) trials of six combinations of visual and support surface conditions in one-legged stance. Modified visual Dome and Foam Test, including eyes open (EO)/eyes closed (EC).	Dancers demonstrated better balance particularly in challenged visual and surface conditions. Dancers employed successful movement strategies to maintain balance.	Low
Golomer *et al*, (1997) [18]	Experimental	Dancers n=31; 15(M), 16(F) 18.1±0.9yrs (M) 17.4±1.1yrs (F) Acrobats n=23; 11(M), 12(F) 18.8±3.5yrs (M) 17.0±3.0yrs (F) Untrained n=21; 10(M), 11(F) 17.5±2.2yrs (M) 19.7±2.6yrs (F)	Stabilometer; four conditions: two visual (EO/EC), for each of two positions: anteroposterior (AP)/lateral equilibrium.	Untrained participants, irrespective of sex, were least stable. Acrobats were more stable than dancers.	Low
Golomer *et al*, (1999a) [19]	Experimental	Ballet dancers from Paris Opera, France n=30(M): 15 dancers (“quadrilles”) 18.1±0.9yrs 15 dancers (“coryphées”) 23.8±2.2yrs	Stabilometer (“seesaw”); three frequency bands (0-0.5 Hz, 0.5-2 Hz, 2-20 Hz); 4 conditions: standing balance in AP and lateral positions, EO/EC for each position.	Dependency on visual information greatest for 18yr olds possibly due to recent accelerated growth affecting trunk proprioceptive regulation. Higher displacement values for AP position for all groups.	Low
Golomer *et al*, (1999b) [16]	Experimental	1) Ballet dancers form Paris Opera, France n=13(M) 23.8±2.2yrs Untrained	1)Stabilometer; frequency 0-20 Hz; 4 conditions: standing balance in AP and lateral positions, EO/EC for each position	Dancers less dependent on vision for postural control and for perception than untrained. No significant correlation between perceptive visual behaviour in rod and frame test (RFT) and dynamic	Low

		n=10(M) 18.8±3.5yrs 2) Professional dancers n=10(M) n=6 (subgroup for both tests) Untrained n=19(M) 24.5±4.5yrs (whole group)	2) Visual perceptual study using the rod and frame test (RFT); frame tilted at 18˚; tested at 12 different tilts (6R, 6L)	equilibrium performance.	
Hugel *et al*,(1999) [14]	Experimental	Ballet dancers from National Ballet of Nancy and Lorraine, France n=18; 6(M), 12(F) 16-35yrs Nondancers n=46 16-37 yrs	Static posturography using a force platform; two protocols: 1) flat footed, (EO/EC). (2) Bipedal or unipedal balance on demi-pointe (EO/EC for bipedal, & EO for unipedal). (F) dancers : bipedal test on pointe (EO/EC); unipedal on pointe (EO).	Dancers only performed better than controls in EO conditions. Similar results for pointe tests (EO/EC) indicate a learning effect for balances on pointe.	Low
Golomer *et al*, (2000) [33]	Experimental	Professional dancers of the Opera n=23; 13(F), 10(M) 23.3±6.7yrs (F) 24.1±1.5yrs(M) Untrained n=18; 11(F), 7(M) 19.7±2.6yrs (F) 24.3±3.0yrs (M)	Seesaw; four conditions: two visual (EO/EC), for each of two positions (AP & lateral tilts); angular acceleration measured only for one oscillation plane; two spectral bands: 0-2Hz and 2-20Hz	For lower frequency bands, difference between EO/EC in two positions higher for untrained; higher frequency results showed diff. between EO/EC higher for dancers. (M) dancers used proprioception more than (F) dancers, but performed similarly in dynamic equilibrium tests.	Low
Perrin *et al*, (2002) [17]	Experimental	Ballet dancers from National Ballet,,Nancy & Lorraine,France n=14(F) 22.1±4.5yrs Judoists n=17(M) 24.8±4.5yrs Nondancers n=42; 21(M), 21(F) 23.9±4.2yrs	Static and dynamic balance tests using a force platform. Static: centre of foot pressure (CFP) recorded, (EO/EC). Dynamic: slow rotational oscillations, 4˚ amplitude, frequency of 0.5Hz, (EO/EC)	Only judoists were able to maintain a better balance control than controls in all tests; in EO tests judoists and dancers performed better than controls; in EC, dancers displayed the worst balance control. The combination of EC and a moving support was challenging for dancers.	Low

Barcellos *et al*, (2002) [60]	Experimental	Ballet dancers n=4(F) 21.60±1.29yrs	Force plate; motion analysis cameras; parallel balances (20s), (EO), en pointe and standing	Significant differences in AP velocity in pointe position compared to standing.	Low
Simmons (2005a) [20]	Randomised order of tests	Ballet dancers from community dance companies and university n=17(F) 21.4±0.68yrs Untrained n=17(F) 21.6±0.39yrs	Cutaneous foot sensitivity tested with a Semmes-Weinstein monofilament test; dual force plates enclosed by three-sided visual surround; six randomised sensory organisation tests (SOT): SOT 1 & 2 standing (EO/EC), SOT 3 visual surround matched AP sway of participant's estimated CoG (EO), SOT 4 visual surround stationary but force plates rotated in ref to participant's AP, SOT 5 same as SOT 4 but EC, SOT 6 both surround and force plates referenced to participant's AP sway.	No statistical difference in AP sway between dancers and controls for SOT 1-3; dancers had significantly greater AP body sway than controls in SOT 4; greater use of hip strategy to maintain balance for dancers in SOT 5 & 6; ballet dancers were significantly less stable in AP direction during static balance when forced to rely on visual and vestibular input (SOT 4) or vestibular input alone (SOT 5) supporting a notion of a shift in sensory weighting from visual to somatosensory information in ballet dancers.	Low
Simmons (2005b) [34]	Computer-controlled randomised inter-trial-intervals	Ballet dancers from community dance companies and university n=15(F) 21.4±0.76yrs Untrained n=16(F) 21.2±0.47yrs	Dual force plates enclosed by visual surround; force plates rotate upward 8˚ at rate of 50˚ per second; 20 trials of standing balance; EMG electrodes parallel to long axis of medial gastrocnemius and anterior tibialis muscles of each leg.	No significant difference between groups for short-latency (SL) or medium-latency (ML) responses. However, dancers had significantly faster and more consistent long-latency responses than controls.	Low
Schmit *et al*, (2005) [35]	Randomised order of trials	Dancers from Dance Dept, University of Cincinnati College Conservatory of Music n=10; 5(F), 5(M) 20 yrs (mean) Varsity track team runners, U of C, served as control group n=10; 5(F), 5(M)	Force platform; four trials each of four experimental conditions of vision and support in standing balance: EO/rigid; EO/foam, EC/rigid, EC/foam.	Results showed postural sway of dancers was less regular, less stable, less complex and more stationary than that of track athletes. Difference between EO and EC conditions was greater when participants stood on the foam.	Low

		19.5yrs (mean)			
Coutts *et al*, (2006) [69]	Experimental	Contemporary dance students from Northern Rivers Conservatorium and regional dance schools n=9; 6(F), 3(M) 18.8±5.1yrs	Pre- and post-tests consisting of: Subjective Exercise Experience Scale (SEES); five trials of a right-leg flat-footed arabesque on a force plate; GRF variability and CoP calculated; incremental fatiguing dance protocol conducted on all participants; Rate of Perceived Exertion (RPE) conducted during dance protocol.	Stability indices showed arabesques to be inherently unnstable postures. No changes in the stability indices were observed. This may have been due to rapid recovery during the post-dance protocol SEES completed before the post-dance arabesque trials.	Low
Denardi *et al*, (2008) [61]	Experimental	Ballet dancers n=8; (F) 18.5±1.7yrs	Two video cameras (frequency 60Hz) were used: one focusing on participants' eyes, the other on their head & shoulders; five trials of a pirouette en dehors from 5th position on L leg support (EO/EC).	Postural stability deteriorated with EC; long initial gaze fixation durations and reduced body oscillations were noted; clear sequencing of trunk, head and gaze was observed in turns, in response to teachers' cues.	Low
Gerbino *et al*, (2007)[40]	Set test condition order	Collegiate dancers trained in modern dance and ballet n=32(F) 20.3±1.5yrs Soccer players n=32(F) 19.7±1.7yrs	Matscan pressure mat; COP variability; center acquisition time (CAT) used to quantify ability to "center"; barefoot unipedal balance (R leg only); three trials each of five test conditions: EO, EC, foam mat, landing from jump, landing from side weight shift (cutting); jump tests: two steps & hop (L and R ft); CAT, sway index, sway velocity and sway path length measured.	Overall, dancers scored better in 5 out of 20 measures; in sway index and CAT scores dancers demonstrated better balance; training effect and selection of R leg as test leg suggested as factors; large STD in EC for both groups.	Low
Golomer *et al*, (2009a) [62]	Set order of trials.	Ballet dancers n=8(F) 19±1.5yrs Untrained	Vividness of Movement Imagery Questionnaire (VMIQ); Vicon 8 system, nine cameras; five trials for each of four types of rotation:	In preferred pirouettes, en bloc shoulder-hip stabilisation demonstrated by dancers but not untrained; in non-preferred turns en bloc not maintained	Low

		n=7(F) 19±1.5yrs	left foot clockwise (LCW), left foot counter-clockwise (LCCW), (RCW), (RCCW), all EO. Supporting foot displacement measured in pirouettes.	in dancers CCW on L support leg or in any condition by untrained; at end of turns untrained were en bloc for CCW (preferred direction) on both legs.	
Golomer *et al*, (2009b) [59]	Investigators blinded to participants' perceptual styles, but set order of trials to reduce fatigue	Ballet dancers n=10(F) 19±2yrs	Vividness of Movement Imagery Questionnaire (VMIQ); Vicon 8 system, nine cameras; five trials for each of four types of rotation: left foot clockwise (LCW), right foot counter-clockwise (RCCW), (LCCW), (RCW), all EO. Sequence repeated with EC. Supporting foot displacement measured during the pirouettes.	Kinesthetic (K) dancers demonstrated more support foot (SF) displacement in the CCW turn than in the CW turn. (K) dancers showed no significant effect of vision on SF displacement. Visual/Kinesthetic (V/K) dancers had higher SF displacement with EC. (V/K) dancers less stable with EC, but (K) dancers had similar stability with EO or EC.	Low
Bruyneel *et al*, (2010)[63]	Experimental; randomly tested	Ballet dancers n=20; 6(M),14(F) 22.4±5.06yrs	GRFs (AP, ML, V) were recorded on a forceplate (MATLAB v.6) Randomly assigned tests: leg extensions, 45˚, anterior, lateral, posterior; EC/EO.	EC increased AP, ML, and V impulsions. Suggested learning effect for enhanced balance results in adult group, but visual dependence for postural control.	Low
Golomer *et al*, (2010) [36]	Experimental	Professional ballet dancers n=7(F) 19±1.6yrs Untrained n=7 19±1.3yrs All participants (n=14) were dextral (right handed)	Seesaw platform on top of a force platform; sampling frequency of 40Hz; AP (pitch) and lateral (roll) directions; one-legged balance (L & R); two visual hemifields were isolated, highlighting hemispheric asymmetry (visual target)	In pitch sway, higher instability for all with left visual hemifield suppression. Visual restrictions had no effect on roll stability for untrained. Similar stability for AP sways for all participants. Higher instability for dancers in roll (L) conditions with left visual hemifield suppression; dancers may depend more on vision to maintain equilibrium.	Low
Batson (2010) [76]	Testers were randomised; randomised testing of the m(SEBT)	Dance students from Trinity Laban Conservatoire of M & D, UK (Grp A), and North Carolina School for the Arts, USA (Grp B) Grp A: n=22; 20(F), 2(M)	Two tests: Star Excursion Balance Test (SEBT), modified SEBT (mSEBT); modifications were: 1) timed test, (2) timed test with cognitive interference (answering questions), (3)	29 participants completed tests; use of variable strategies used by dancers. Inter- and intra-dancer variability was observed. Foam tests often resulted in dancers' vision shifting downwards & some falls were reported. Factorial	Low

		20.6±1.5yrs Grp B: n=15; 13(F), 2(M) 19.8±1.5yrs	standing on foam pad with self-selected pace.	analysis of SEBT suggests that some SEBT spokes are redundant.	
Cloak *et al*, (2010) [31]	Randomly assigned groups; randomised order of SEBT reach directions. Intervention study; RCT	Dance students from a university dance department n=38 (F) 19±1.1yrs Assigned as follows: Vibration training group n=19 Controls n=19	Pre-tests, participants completed Cumberland Ankle Instability Tool (CAIT) questionnaire; R Scan pressure mat; two trials of one-legged bare foot stance (EO) measuring COP; three trials of SEBT tested on unstable ankle; EMG demi-pointe stance of 30s; whole body vibration training (WBVT) grp: 6 wk progressive programme of bare foot single leg dynamic exercises (bi-weekly).	Static and dynamic balance significantly improved; significant improvements in SEBT anterior, anterior medial, medial, and anterior lateral for WBVT group; no significant difference in % decrease in mean power frequency (MPF) between groups in demi-pointe stance, but significant difference in COP between groups.	High
Caplan *et al*,(2011) [70]	Experimental	Professional dancers from a contemporary dance company n=7; 4(F), 3(M) 32±7yrs	Rotating platform placed on top of force platform; static one-legged balance; single trial; heel of raised leg in contact with support leg and hands on knee of raised leg; stance position and same angular velocity as that used in choreography	Participants able to maintain posture for 66±32 seconds; Six participants showed reductions in AP and ML sway; one participant showed a slight increase in AP and ML sway. No statistical differences found but reductions in sway showed large effect.	Low
Lin *et al*, (2011) [15]	Sequences randomised by drawing	Dancers Injured (recent past injury) n=11(F) 19.7±2.4yrs Uninjured n=11(F) 18.8±3.1yrs Non-dancers n=11(F) 20.0±1.9yrs	Force plate; centre of pressure calculated; four x 15s trials of each condition: single-leg stance (EO/EC), first position, fifth position, and en pointe; non-dancers: single-leg stance only.	Injured (I) dancers had greater maximal displacement in ML direction and total trajectory of COP than other two groups. In first and fifth positions (I) dancers demonstrated greater STD of COP in ML and AP directions, compared with uninjured (UI) dancers. On pointe, (I) dancers had greater maximal displacement in ML and AP directions compared with (UI) dancers.	Low
Pappas *et al*,	Randomised order	Dancers	Force plate; three trials of R leg	(F) dancers demonstrated longer TTS	

(2011) [73]	of conditions	n=36; 23(F), 13(M) 28±5 yrs (F) 26±4 yrs (M)	hop on each of the five floor conditions: flat, four inclined (anterior, posterior, medial, lateral); time to stability (TTS) calculated for each landing; data analysed from the first 5s; participants' own athletic shoes.	in both directions (AL, ML); neither floor inclination or floor x gender had an effect on TTS. Proprioceptive feedback, shoes, and ankle laxity may be factors in the gender differences. Landing on inclined floor did not cause dancers to land with an increased TTS.	Low
Rein *et al*, (2011) [77]	Randomised order of testing	Professional dancers n=20(F); 10(M) 27±9yrs Amateur dancers n=20(F); 10(M) 34±11yrs Controls n=15(F); 15(M) 31±13yrs	Biodex Stability System (tilting); three test evaluations (EO) were performed for each position condition: Conditions were: with level 2 (unstable) or level 8 (stable), both legs, right leg, and left leg.	Professional dancers showed better overall stability index (OSI), ML, and AP scores than both other groups at both levels and in all standing conditions; they balanced more in the anterolateral and less in the posteromedial part of their feet when compared to amateur dancers and controls.	Low
Clark *et al*, (2012) [30]	Experimental	Contemporary dance students from a dance conservatoire n=85; 34(M), 51(F) 19.56±2.68yrs (M) 19.16±2.08yrs (F)	Self-reported previous injury information collected; RSscan Footscan pressure pad; two trials of each balance tasks on the R & L leg: (1)one-legged stork test 10s (EC), (2) modified rond de jambe 6s (EO).	Participants exhibited greater postural stability when balancing on L leg; (F) dancers exhibited greater postural stability than (M) dancers.	Low
Ambegaonkar *et al*, (2013) [44]	Randomised order of tests. Reliability and error scores incl.	Dancers (primary form: modern dance) n=18 (F) 20.0±0.8yrs Nondancers n=15 (F) 22.1±2.8yrs	Balance Error Scoring Sysyem (BESS): six conditions, three stances (double leg, single leg, tandem) , two surfaces (rigid floor & foam pad) ; reliability between .50 and .88; (EC); SEBT: three testing directions anteromedial (AM), medial (M), posteromedial (PM); reliability between .84 and .92; Modified Bass Test of Dynamic Balance (BASS): alternating leg stance; combination of dynamic & static	Dancers demonstrated better scores than those of non-dancers for BESS, and for the SEBT test directions (M and PM). Dancers did not differ from the non-dancers for the BASS.	Low

			balance; reliability of .75; alternate jumps marker to marker (total of 10).		
Morrin *et al*, (2013) [71]	Randomised order of conditions (warm up protocols only)	Contemporary dancers n=10; (F) 27±5yrs	RS foot scan measuring CoP; warm up stretch protocols looking at acute effects on performance indicators including balance; four separate tests of 3 trials of a 5s demi-pointe balance in 5th position.	Dynamic stretch and combination stretch indicated lower CoP movement than static and non-stretch. Balance performance was significantly affected by combination stretch.	Low
Wyon *et al*, (2013) [74]	Randomised order of conditions	Undergraduate dance students n=28; (F) 19±0.64yrs	Force platform; three trials on R and L leg under four conditions: barefoot, ballet flats (2mm thickness), jazz shoes (7mm), jazz sneakers (30mm); single leg landing in jump protocol taking off from two feet; dynamic postural stability index (DPSI)	Significant differences between midsole thicknesses found for both DPSI and vertical stability (VSI); increased midsole thickness had negative effect on landing stability; greatest increase in instability was the V dimension, and to a lesser extent the ML measurement.	Low
da Costa *et al*, (2013) [13]	Randomised order of testing	Non-professional ballet dancers n=14(F) 18.4±2.8yrs	Pressure platform; One-legged stance in three ballet poses: attitude devant, attitude derriére, attitude à la seconde; three trials for three ballet poses under two conditions: barefoot (BF) and "slippers"(S)	Smaller COP oscillation areas and AP COP oscillations were produced in BF performances for attitude devant and à la seconde. No significant differences among ballet poses when performed with (S). Attitude à la seconde produced the smaller COP oscillation areas, lower AP COP oscillations and lower ML velocities than the other poses.	Low
Lin *et al*, (2014a) [64]	Experimental	Superior experienced ballet dancers(SE) n=9 (F) 18.2±1.0 yrs Experienced dancers (E) n=9(F) 18.3±5.7yrs	Motion analysis; force plate; single leg stance in retiré position beginning and ending in fifth position; three trials for the dominant and non-dominant leg respectively.	E dancers had better balance when standing on the non-dominant leg; the SE dancers had similar postural stability between legs. SE dancers had a greater maximum COM-COP distance in the AP direction.	Low

Lin *et al*, (2014b)[65]	Experimental	Experienced ballet dancers n=13(F) 17.77±3.39yrs	Motion analysis; force plates; five trials of single pirouette en dehors with dominant leg support	Experienced dancers used the translation strategy (maintaining trunk axis vertically) and visual input as a stabilisation strategy	Low
Pérez *et al*, (2014)[75]	Randomised order of conditions	Undergraduate dancers from the Spanish Royal Conservatory of Dance n=18(F) 23.32±2.58yrs Non-dancers n=30(F) 22.23±1.79yrs	Stabilometer; two conditions (EO and EC); 30s barefoot stance. Complexity of postural sway dynamics calculated by Sample Entropy and Permutation Entropy.	Dancers performed better only in the EO test. Dancers reduced their complexity behaviour in the EC test.	Low
Hopper *et al*, (2014)[55]	Non-randomised order of tests; randomised order of legs	Professional ballet dancers n=9(no gender listed) 18.78±0.40yrs Pre-professional n=6(no gender listed) 17.00±0.00yrs Recreational n=8(no gender listed) 20.62±0.33yrs	Force plate; total area of COP with 95% CI; 5 single pirouettes on preferred leg; two baseline and post-turn tests on both legs in 10s coup de pied position immediately, 30s and 60s after turn task. Followed by fatigue test: 30s of ballet jumps and repetition of coup de pied tests in 3 time intervals.	No differences between dominant & non-dominant legs in static balance tests. Professional dancers showed better balance after turns. Fatigue test: no significant differences between groups but pre-professional and recreational showed significant increases in sway.	Low
Li *et al*, (2014)[66]	Experimental	Professional ballet dancers n=4(F) 18-21yrs	Force plate, EMG, motion analysis cameras; test: 1 pirouette on 1 leg	Ankle and knee strength, and movement control of support leg found to be key factors in balance control; core strength and proprioception seen as important in postural control.	Low
Krityakiarana *et al*, (2016)[37]	Randomised order of tests	Thai classical dancers n=25(F) 21.23±0.46yrs Non-dancer controls n=25(F) 21.16±0.38yrs	Force plate; mSOT protocol: 3 x 20s trials each of 4 conditions: EO, EC, EO-SS (sway surface), EC-SS; 3 x 20s trials each of 4 conditions: mSOT + dynamic head tilt (DHT)	Thai dancers had better postural stability than non-dancers with significant differences in all tests except the mSOT with EO.	Low

Ambegaonkar *et al*, (2016) [72]	Cross-sectional study design; experimental; set trial order	Collegiate modern dancers n=15(F) 18.3±0.5yrs	SEBT (Y-balance components); three trials each of anterior, posteromedial, & posterolateral reaches on R & L leg.	Lower extremity (LE) hypermobility and balance showed moderate to good positive correlation.	Low
Casabona *et al*, (2016) [67]	Randomised order of tests	Professional ballet dancers n=10(F) 23.7±2.5yrs Untrained n=10(F) 27.6±3.5yrs	Force platform; five trials of 30s each for five stances: parallel (10cm), parallel (20cm), extra-rotation (15cm & 20˚ rotation), "duck" (140˚ rotation), tandem.	Significant differences shown between groups for the "duck" stance (familiar to dancers). Benefit from ballet limited to specific foot configuration.	Low
Kilroy *et al*, (2016) [56]	Randomised test order	College dancers n=7(F) 18-23yrs College non-dancers n=7(F) 18-23yrs	Force plate; three trials of 30s for each of four single-leg stance conditions: dominant leg support with athletic shoe (S), dominant leg support barefoot (BF), non-dominant leg support (S), non-dominant leg support (BF).	Between groups, non-dancers were more unstable with significant differences in AP and ML (GRF), and balance time. Within groups, dancers were more unstable on non-dominant leg (S & BF).	Low
Zaferiou *et al*, (2016) [68]	Participants selected the order of turns	Professional & pre-professional ballet & contemporary dancers n=10(F) 20.40±3.17yrs	Forceplates; motion capture system; between 5-7 trials per turn condition: piqué en dedans (single & double), pirouette en dehors (single & double); self-selected ballet shoes and stance limb.	In initiation phases, the piqué showed significantly larger center of mass (CM) velocity towards the base of support (BoS). In turn phases, the COM was more vertically aligned with the BoS in pirouette than piqué. Reaction forcess were regulated relative to the COM as rotational demands increased in both turns.	Low

Table 2. Multi-joint postural coordination

Study	Study Design	Participants	Method	Outcome	Grade
Thullier *et al*, (2004) [41]	Experimental	Elite ballet dancers n=6 (no gender described) Gymnasts n=6	Motion analysis; Participants drew single ellipse with R or L foot tip in horizontal plane; ballet shoes worn; orthogonal projections of angular rotation of thigh and shank	Dancers & gymnasts were equally stable. Dancers were more successful in reproducing orientation & shape of the referent ellipses.	Low
Schmitt *et al*, (2005) [51]	Experimental	Dancers in State Academy n=42; 31(F), 17.6±2.1yrs 11(M), 18.5±1.8yrs Untrained n=40; 29(F), 19.1±3.0yrs 11(M), 20.6±3.6yrs	One-legged standing test barefoot on a mat; conditions: 1m on one leg EO, three trials of 1m balance on alternate legs EC; repeated after 5 months.	Dancers exhibited better balance than the untrained controls. There was no further enhancement in the dancers' performance after five months.	Low
Kiefer *et al*, (2011) [42]	Experimental	Professional ballet dancers n=28; 10(M), 18(F) 23.59±3.99yrs Untrained n=28; 10(M), 18(F) 23.39±4.99yrs	One-legged balance whilst tracking computer-generated visual target with head; R or L leg; low frequency (0.2Hz) and high frequency (0.6Hz). Four trials (one per condition).	Dancers exhibited less variable stable ankle-hip coordination, and a less deterministic ankle-hip coupling compared to controls.	Low
Bronner (2012) [52]	Experimental	Pre-professional dancers Expert: n=9; 5(M), 4(F) 24.9±1.0yrs Advanced: n=9; 2(M), 7(F) 19.6±0.5yrs Intermediate: n=9; 4(M), 5(F) 19.8±0.5yrs	Motion analysis system; six trials with R leg as gesture limb in a développé arabesque (90˚) protocol.	Differences found in postural pelvic control and intra- and inter-limb coordination. Intermediate (INT) group showed more variability in both dynamic and static postural control than either the Advanced (ADV) group or the Expert (EXP) group.	Low
Jarvis *et al*, (2014) [53]	Experimental	Professional dancers n=10(F) 27.1±3.5yrs Non-dancers n=10(F) 24.8±2.2yrs	Motion analysis system; force plates; 20 consecutive bipedal jumps; rate of 95bpm;	Dancers had lower intersegmental coordination variability than non-dancers for lower extremity (LE) sagittal, frontal, & transverse plane couplings, and sagittal plane trunk couplings.	Low

Table 3. Studies investigating laterality and balance

Study	Study Design	Participants	Method	Outcome	Grade
Guillou *et al*, (2007) [38]	Randomised experimental conditions	Dancers from Paris Opera n=7(M); 18±0.8yrs Acrobatic gymnasts n=9(M); 19.1±3.6yrs Prof soccer players n=10(M); 17.1±1.1yrs Untrained n=10(M); 21.4±5yrs	Seesaw platform; four conditions: support leg (R & L), and pitch & roll directions; single-leg stance; two frequency bands (0-2Hz & 2-20Hz).	Results for frequency band only significant in roll direction; results showed lateral body balance more important to regulate than AP in a dynamic condition. Physical expertise reduced the dependence on visual &/or vestibular information in roll direction. Soccer players' asymmetrical equilibrium training led to sensorial reorganisation of the L support leg, minimising role of proprioception.	Low
Mertz *et al*, (2012) [39]	Randomised order of tasks	Ballet dancers from university n=30; 23(F), 7(M) 19.6±1.1yrs	Force plate; three trials each of four bipedal jump tests: landing L foot front, landing R foot front, entrechat trois (jump with a beat) landing on R foot, entrechat landing on L foot; ballet shoes worn; laterality questionnaire.	No differences found between preferred leg and non-preferred leg; AP sway and ML sway represent slightly different motions within the foot in AP and ML directions due to use of turn out in feet positions. No differences found in postural sway (AP and ML).	Low
Lin *et al*, (2005) [54]	Experimental	Ballet dancers n=13 (gender not stated but assumed F) 19.15±1.9yrs	Motion analysis system; force platforms; one of three 1s trials in static first position and three of five 5s trials of relevé en pointe were analysed.	Similar ROM & excursion patterns but different initial moment exertions on dominant and non-dominant sides and significant differences in peak moments. Dominant side had a greater moment range thus likely to be primary controller of balance.	Low