Analysis of Pelvic Alignment in University Ballet Majors

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Abstract

Classical ballet technique emphasizes proper alignment of the pelvis to optimize dancer performance. A series of three experiments was conducted in a major university ballet program to determine: 1. the average degree of pelvic tilt for freshman ballet majors, 2. the degree of pelvic tilt acceptable to university ballet teachers, and 3. whether an individual tutoring intervention could improve pelvic alignment in dancers who displayed a high degree of anterior pelvic tilt. Experiment 1 showed that anterior pelvic tilt for 17 freshman ballet majors averaged 13.4°. Experiment 2 revealed a mean anterior tilt of 11.4° for photographs rated as *acceptable* tilt by ballet teachers at the same university. Experiment 3 showed that three dancers who participated in six hours of individual tutoring improved their pelvic alignment by 3° to 4°, enough to move two of the dancers into the *acceptable* range. These studies suggest that a moderate degree of anterior pelvic tilt may be common and acceptable for university ballet majors, and they show that dancers with excessive anterior tilt can improve their alignment with as little 6 hours of individual tutoring.

Dance is an art form where perfection results from a delicate balance between artistry and physical skill. Classical ballet training focuses on perfecting alignment of the human skeleton in service to both purposes. What constitutes ideal pelvic alignment for dancers has yet to be demonstrated empirically. While the logic of efficient biomechanics might suggest the pelvis needs to balance on the heads of the femurs,[1,2] the relative position of specific bony landmarks when the pelvis is balanced will probably vary by individual dancer, and from movement to movement. Research is needed to clarify this issue. This study focuses on dancer pelvic alignment on the sagittal plane.

Kendall, McCreary, and Provance defined *neutral* pelvic alignment as a point where the two anterior superior iliac spines (ASIS) are on the same vertical plane as the symphysis pubis.[3] Fitt defined neutral alignment as having the ASIS and the posterior superior iliac spines (PSIS) on the same horizontal plane.[4] Using either convention, possible misalignments on the sagittal plane are tilting the top of the pelvis too far forward (anterior tilt) or tilting the top of the pelvis too far backward (posterior tilt).[3,4-8]

Excessive pelvic tilt, particularly anterior tilt, appears to be a common technical fault among pre-professional ballet dancers, and may be caused by an imbalanced use of muscles that control the pelvis and lumbar spine, tight hip flexors, or structural anomalies. Several dance training authorities suggest that misalignment of the pelvis in dancers may lead to vertebral stress and knee, foot, and ankle injuries due to compensatory movements and excess muscle tension.[4-6] Efficient pelvic alignment, on the other hand, may facilitate efficient movement in general and efficient specific action at the hip and lumbar spine.[1,4] Learning to achieve a more neutral pelvic alignment might help dancers succeed in the highly competitive field of ballet.

Several studies provide a starting point for further research on this topic. Gamboian and colleagues analyzed the effectiveness of somatic training to improve pelvic alignment in university dancers.[5] These

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investigators found that technique class alone did not improve pelvic alignment, however adding somatic training did lead to improvement in some individuals. They recommended the use of repeated measurement across days and within-subject research designs to accommodate day-to-day and between-subject variability. Welsh and colleagues used a repeated measure, within-subject research design to evaluate the effects of back strengthening on university dancers.[9] McMillan and associates[7] suggested that Pilates-based exercise can improve posture and body control. They concluded that alignment improvements were probably attributable to increased motor control.

Pelvic alignment measurement systems vary across studies. Some used a two-dimensional kinematic analysis system such as the Peak Performance analysis[5,10] or Vicon kinematic system.[11] While lab-based measurement systems offer a technologically sophisticated approach to assessing alignment, they place dancers in an unfamiliar environment that may affect performance and alignment. A few researchers have used alignment measurement approaches that are easier to adapt to the dancers training environment.

McLain and coworkers[8] placed reflective markers on dancers' anterior superior and posterior superior iliac spines and videotaped them in front of a large grid. Expert judges rated the dancers' alignment from the videotapes. Fitt and colleagues[12] placed reflective markers on these same bony landmarks and took side-view, still photographs so the angle of pelvic tilt could be measured later. Independent of the measurement method employed, dance researchers have emphasized the need for repeated measurements and within-subject comparisons to reveal and accommodate individual variation.

We conducted three studies to examine pelvic alignment in dancers in a professional training program in ballet at a major university. The experiments assessed: 1. the average degree of pelvic tilt for first-year ballet majors, 2. the degree of pelvic tilt acceptable to the experts who teach them, and 3. whether pelvic alignment could be improved through individual tutoring. Experiment 1 was a descriptive study of the degree of pelvic tilt in first-year dancers in a university-based professional training program in ballet.

Experiment 1

Participants and Setting

Seventeen of 25 first-year, female ballet majors volunteered to participate in Experiment 1 in response to an announcement made in their dance injuries class. All were between 17 and 20 years old and had been selected by audition for the professional training program. Participants signed consent forms and the university's Institutional Review Board approved all three studies.

First-year ballet majors were required to attend daily 110-minute ballet technique classes as well as 50-minute pointe technique classes three times a week, and a 50-minute character dance class twice a week. The dancers had a variety of technique instructors, each with their own intention and focus. None of these classes followed a specific, pre-formulated ballet technique. A diverse combination of classes is probably typical of many dance programs in higher education.

Measurement

A measurement procedure was developed to assess each dancer's degree of pelvic tilt while dancing. The procedure was comparable to a radiographic approach used by Crowell and colleagues[13] as a criterion comparison for clinical assessments. We adapted the procedure for use in an environment analogous to ballet technique class. All assessments were performed in the ballet studios where the participants attended daily classes. The measurements were conducted, one dancer at a time, always following ballet technique class to insure the dancers were warm. The dancers were taught three ballet barre combinations. The first combination, pliés, included a phrase of two demi-pliés, one grand plié, and port de bras combining torso and arm movements. The second was a tendu combination from first position combining a demi plié in fourth or second position with a demi rond de jambe and slow tendus into first position. The final combination was a tendu from fifth position. This combination utilized a transfer of weight through fifth position, quicker movements, and a relevé in fifth position with a change of the feet. All combinations were typical of a ballet technique class for dancers at this level. While they were conceptually simple, the combinations did challenge the dancers by demanding quick thinking and transfer of weight.

Three-dimensional reflective markers were placed by palpation on the dancers leotards at the anterior and posterior superior iliac spines (Fig. 1). The first author placed all markers to minimize variability in marker placement. Crowell and colleagues found inter-tester assessment of the ASIS and PSIS alignments to vary as much as 5°, while intra-tester assessments varied by no more than 2°.[13] To match conventions adopted by several authors,[4-6,11-13] pelvic alignment was measured along the sagittal plane and compared to horizontal, as 0°. We defined tipping the pelvis so the anterior superior iliac spines moved lower

Figure 1 Example of marker.

than the posterior superior iliac spines as *anterior tilt* and tipping the pelvis so the posterior spines moved lower than the anterior spines as *posterior tilt*. Accordingly, the dancer in Figure 1 is displaying anterior tilt.

A tripod-mounted video camera (Cannon GL1) was placed perpendicular to the dancer. The camera was leveled and its height was adjusted so the center of the lens was one meter from the floor, which was at hip level for most dancers. The degree of zoom was set to marginally more space than was used by the dancers while performing the three barre combinations to insure consistency across observations. A black drape was hung on the wall behind the dancers to provide a consistent contrasting background against which to record their alignment.

The dancers performed the ballet combinations to pre-recorded music while being video recorded. From the video recordings of each session, still images were taken from eight points in the combinations such that they represented the range of movement included in the combinations where dance teachers might expect the pelvis to be neutrally aligned. Three images were taken from the plié combination, three were taken from the first tendu combination, and two images were taken from the last tendu combination. The specific locations for these stills were as follows:

1. Bottom of demi-plié in first position,
2. After coming up from the grand plié in fifth position,
3. After the circular port de bras in fifth position,
4. After rond de jambe from tendu back to tendu side,
5. After the last quick tendu front,
6. Top of the relevé in first position,
7. Tendu side during first set, and
8. Relevé fifth position right foot front after degage switch from the back.

The eight still images were measured using image analysis software available in the public domain (ImageJ: rsb.info.nih.gov/ij/index.html). The software allowed an angle in degrees to be determined by comparing a line drawn between the two reflective markers to the horizon. We assigned positive numbers to degrees of anterior tilt and would have assigned negative numbers if any dancers had displayed posterior tilt.

The measurements were summed and divided by eight to yield a mean for each session. This provided an estimate of the degree of pelvic tilt each dancer used when neutral alignment might be expected. The process was repeated once a week for three weeks for each of the 17 participants. The means from each of the three sessions were averaged to determine a three-week mean for each dancer. An overall mean for all the participants was also calculated.

To assess the reliability of the measurements, 79 of 700 still photographs (11%), were drawn at random and independently assessed by a second observer. Measurements were compared photo-by-photo and an agreement scored when the two measurements differed by less than 2°. Reliability was calculated by dividing the number of agreements by the number of agreements plus disagreements, and converting the resulting proportion to a percentage. Overall reliability was 81%.

Results and Discussion

Table 1 displays the individual measurements and weekly and 3-week means for each of the 17 participants in Experiment 1. The results show that all participants had some degree of anterior pelvic tilt. Individual measurements ranged from 7.8° to 20.5°. Three-week means for individual dancers ranged from 8.9° to 18.3°. The overall mean for all 17 dancers was 13.4° of anterior tilt. Anterior pelvic tilt was highest for 10 of the 17 participants during Week 3.

Pelvic alignment varied from dancer to dancer and from week to week for individual dancers. This variation is consistent with previous findings and supports the call for repeated measurements when studying pelvic alignment in dancers.[5,7] Possible explanations for the alignment variability might include changes in muscular tightness, energy level, or dancer focus. Fatigue, a desire to impress the researcher, and settling into old habits may have contributed to the increase in anterior tilt for many dancers during the three-week observation period.

Table 1 Degree of Anterior Pelvic Tilt

Dancer	Week 1	Week 2	Week 3	Mean	Std. Dev.
1	9.3	7.8	14.8	10.6	3.7
2	13.7	13	*	13.4	0.5
3	10.9	13.6	18.8	14.4	4.0
4	10.8	12.5	15.9	13.1	2.6
5	13.7	14.4	*	14.1	0.5
6	9.9	9.8	11.5	10.4	1.0
7	9.5	11.6	10.9	10.7	1.1
8	11.5	12.8	15.8	13.4	2.2
9	10.7	15.3	15	13.7	2.6
10	11.2	13.9	19.1	14.7	4.0
11	14.2	14.8	20.5	16.5	3.5
12	10.4	4.5	11.8	8.9	3.9
13	15.7	16.7	*	16.2	0.7
14	13.1	16.4	13.7	14.4	1.8
15	16.6	15.3	14.3	15.4	1.2
16	16.2	18.9	19.8	18.3	1.9
17	8.2	11.5	9.8	9.8	1.7
Group Average				13.4	2.2

*Dancers 2, 5, and 13 completed only two weeks of assessments. Since there was so little variation, we kept them in the sample.

Mean anterior tilt for dancers in this study was consistent with prior research conducted with dancers,[5,12] and somewhat higher than ranges (4° to 16°) recorded for other populations using similar measurement procedures.[11,13,14] Experiment 2 used the images from Experiment 1 to determine the degree of pelvic tilt that is acceptable to teachers of ballet.

Experiment 2

Method

Four university ballet instructors with knowledge of dance science and proper alignment were asked to participate. Eighteen still images were chosen from Experiment 1 based on the following selection criteria: the pelvis and alignment were easily seen against the black background, they represented all of the eight recorded positions, and they represented a range of pelvic tilt (7° to 19°) that approximated the range measured in Experiment 1. The images were modified to remove the reflective markers and blur the faces to disguise the dancers' identity. All 18 images were shown to the instructors in random order and they were asked to place each image into one of three categories—acceptable, borderline, or unacceptable—based on pelvic alignment. The mean degree of anterior pelvic tilt was determined for each category by averaging the measurements for the images placed in each category.

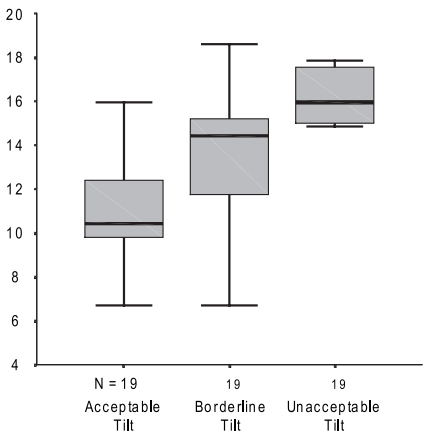

Figure 2 Judges ratings: box plot defining acceptable, borderline, unacceptable pelvic tilt with median values and interquartal range.

Results and Discussion

Figure 2 summarizes the results of the ballet instructors' assessments and they show a distinct difference between the mean degree of anterior tilt for the photos placed in each of the three categories. Particularly notable is a 5° difference between the mean acceptable pelvic tilt of 11.4° (SD 2.95) and the mean unacceptable pelvic tilt of 16.4° (SD 2.93). The mean for the images rated *borderline* was 13.5° (SD 1.70).

The results show that the average degree of anterior tilt revealed in Experiment 1 (13.4°) nearly matched the mean (13.5°) for the photographs judged to be borderline in terms of acceptability to the teachers (Experiment 2). In fact, 12 of the 17 participants exceeded the mean angle for the photos judged acceptable. These results suggest the need for an intervention to improve pelvic alignment in dancers with high degrees of anterior pelvic tilt.

Experiment 3

The purpose of Experiment 3 was to determine whether an intensive, multi-component, individualized training approach could improve pelvic alignment for dancers with excessive anterior pelvic tilt and extensive prior dance training. A within-subject experimental design was employed to permit the use of an individualized training strategy, and to eliminate individual alignment differences as a potential confounding influence on the results.

Participants

Three dancers from Experiment 1 (Dancers 11, 15, and 16) were invited to participate in an individual tutoring program designed to reduce anterior pelvic tilt. The dancers were chosen to participate in Experiment 3 based on alignment tendencies revealed in Experiment 1. All had a high degree of anterior pelvic tilt and, upon interview, expressed a strong desire to improve their alignment. The dancers had the same course schedule and each was exposed to the same daily classes, corrections, and information. Background information was attained though preliminary interviews.

Dancer 16 was 17 years old at the beginning of the study and indicated that she was very aware of her need to improve her pelvic alignment based on repeated corrections given throughout her dance career. Her dance training began at age four and consisted predominantly of ballet, although she also had some experience in modern and jazz techniques. She entered the study with a mean anterior pelvic tilt of 18°. Dancer 11 also said she was exceedingly aware of her misalignment and was becoming increasingly frustrated with her inability to fix the problem. She had focused on ballet training for the past five years and was 18 years old during the study. The results from Experiment 1 revealed a mean of 17° anterior pelvic tilt. Dancer 15, 19 years old, had been training for 13 years in ballet and character dance, and spent a year dancing professionally prior to attending the university. Her initial anterior pelvic tilt was 14°.

Prior to intervention, all three dancers were presented for evaluation to a physical therapist to determine if their individual pelvic structures restricted alignment improvement. Dancer 16 showed tightness in both hips in external and internal rotation as well as a slightly longer right leg. Dancer 11 had a shorter right leg, slight scoliosis to the right, as well as instability and hypermobility in the right hip. Tests on Dancer 16 showed a shorter left leg as well as a tighter left hip in internal and external rotation and in flexion. None of the tests, including Thomas and Patrick tests,[3,15] forecast an inability to achieve a more neutral pelvic alignment and no unusual bony or ligamentous restrictions were detected for any of the dancers.

Although none of the dancers were experiencing lower back or hip pain at the time of the study, Dancer 15 had suffered a stress fracture in her lumbar spine (L3) several years prior and Dancer 11 had experienced low back

and sacroiliac joint pain in the past. All three dancers hoped participation in this study would help reduce their risk of injury in the future and help improve their dance abilities.

Setting and Measurement

Assessments of pelvic alignment were performed once or twice a week as described in Experiment 1 for all three subjects for the next nine weeks. Individual tutoring was conducted on days convenient for the dancers, and following the alignment assessments. Daily technique classes, the alignment assessments, and tutoring all took place in the same studio.

Training Procedure

All dancers added tutoring sessions to their highly structured dance routine. When their time for individual training arrived, each dancer participated in one-hour tutoring sessions twice a week for three weeks, for a total of six training sessions for each dancer. A major focus of the tutoring sessions was increasing awareness and motor control and developing good alignment habits to promote lasting improvements. The individual tutoring approach allowed the experimenter to interact intensively with each dancer and to tailor the intervention to each dancer's specific needs and abilities.

The tutoring sessions were eclectic, providing a wide range of information, skills and experiences for the dancers. A central component was the introduction of a series of Pilates and pre-Pilates exercises designed to help the dancers find and maintain a more neutral pelvic alignment. It has been suggested that such exercises increase strength, flexibility, and control in dance populations.[7,8,12] These exercises focused on the abdominal and lower back muscles, hip flexors, quadriceps, and deep hip rotators. The dancers were given a packet of exercises and were asked to work on them outside of the tutoring sessions as often as possible without compromising their daily routines. It was suggested that they try to incorporate two or three of the exercises into their warm-up before daily technique class. Table 2 provides a list of the exercises. A breakdown of the tutoring sessions by day is as follows:

1. Dancer received an explanation of why good alignment is useful to dancers, a visual analysis of their own still images taken from previous assessment sessions, and a short anatomy lesson using a pelvic model as a visual aide to explain neutral alignment. The first few exercises where introduced.
2. All exercises were taught and explained. Standing and walking with a more neutral pelvic alignment was addressed, and the dancers were encouraged to work toward a more neutral alignment outside the dance studio.
3. Session 2 concepts were repeated with the addition of performing a demi-plié and a tendu in an externally rotated first and fifth position. A focus was placed upon rotating the legs from the hips using the deep rotators and inner thigh muscles while engaging the abdominal muscles to bring the pelvis toward neutral.
4. Relaxation exercises were added to decrease excess muscle tension, enhance awareness, and increase limbs' connection into the center of the body. The exercises taught in the prior sessions were refined.
5. Less time was spent on the exercises and more time was spent performing simple ballet combinations with a more neutral pelvic alignment and good external rotation.
6. Session 5 content was expanded by moving the combinations to the center of the studio. Individual problem areas for the participating dancer were addressed and all of the material covered throughout the sessions was reviewed.

The dancers were encouraged to use the information learned in the tutoring sessions in their daily technique

Table 2 Exercises Taught During Tutoring

Hook Lying Position (supine)	
1	Pelvic Clock: Tip pelvis through 12 positions of clock face
2	Articulated Bridging: Roll up through the spine to support on shoulders and feet
3	Marching in Bridge: Alternating, parallel retires with pelvis lifted to bridge position
Supine with Hips and Knees Flexed to 90°	
4	Supine Marching: Lower alternating heels to floor, torso and spine remain neutral
5	Supine Spine Twist: Rotate lower spine and pelvis to shift knees side to side
6	Single-Leg Stretch: Extend one leg long just above floor, other knee to chest; alternate
Prone (face down)	
7	Cat and Cow: On hands and knees, hyperextend and flex whole spine
8	Swimming: Contra-lateral hip and shoulder extend and flex alternately
9	Child's Pose: Fold at hips, knees, and spine to release hips and lower back muscles
Stretches	
10	I-T Band: Sitting with legs extended, grasp opposite foot and draw leg across centerline
11	Hip Flexor: Keeling lunge with pelvis held as vertical as possible
12	Hip Rotators, supine: One knee crossed-over other, pull knees to chest Hip Rotators, seated: Sitting with folded, crossed legs, fold torso forward

classes. They were also asked how technique class was feeling for them and were free to ask questions at anytime during the sessions. Each session was individualized to the dancer and her particular needs and concerns.

Experimental Design

To permit the intensive involvement with each dancer that the tutoring intervention required, and to remove individual differences as a source of variability, a multiple-baseline experimental design was used to assess the effects of the tutoring on pelvic alignment.[9,16,17] All three dancers' pelvic alignment was measured repeatedly before, during, and following their three-week tutoring intervention. Tutoring was introduced in a staggered fashion, one dancer at a time. Order of intervention was based upon convenience for the dancer. This permitted the direct observation of alignment variability and graphic analysis of the intervention effects. The experimental conditions were as follows:

1. Baseline: Three baseline measurements were taken for each dancer from the weekly means in Experiment 1. Due to the quick transition from Experiment 1 to Experiment 3, these measurements provided a useful baseline.
2. Training for Dancer 16: Starting in week one of the nine-week intervention period and continuing through week three, Dancer 16 received tutoring twice a week. Her pelvic alignment was measured before each tutoring session. Dancers 11 and 15 continued with their daily routines and were measured once a week.
3. Training for Dancer 11: Starting in week four and continuing through week six, Dancer 11 received individual tutoring while Dancer 16 returned to her daily routine and was encouraged to continue to perform the exercises on her own time. Dancer 11 was measured twice a week before her tutoring sessions while Dancers 16 and 15 were measured once a week.
4. Training for Dancer 15: During weeks seven through nine, Dancer 15 received tutoring, while being measured twice a week before each tutoring session. Dancers 16 and 11 continued to be measured once a week.

The repeated measurements allowed each dancer's pelvic alignment during and following tutoring to be compared to her own alignment prior to the intervention, thereby eliminating a major potential source of variability. This combination of conditions constitutes a true experimental design that permits isolation of causal variables by visual inspection of graphically-displayed data, rather than relying on inferential statistical tests.[17]

Social Validity

At the end of the nine-week tutoring intervention, the dancers filled-out a questionnaire to assess their experience in the study. The participants were given no instructions other than to answer honestly. The questions required the dancers to rate (on a scale from 1 to 5) the importance of neutral pelvic alignment for ballet dancers, whether the tutoring program was a good use of their time, and whether the tutoring program helped them improve their pelvic alignment.

Results and Discussion

Figure 3 displays the repeated measurements of pelvic tilt for each dancer during all experimental conditions. The dashed vertical line shows the staggered introduction of tutoring for each dancer. Dancer 16 entered the tutoring sessions with a mean of 18° of anterior tilt. When individual tutoring was initiated for Dancer 16, her degree of anterior tilt decreased to a mean of 15° with only one measurement modestly overlapping the lowest baseline measurement. During this same period, pelvic tilt for Dancer 11 increased temporarily and then returned to baseline levels, and tilt for Dancer 15 decreased initially and then leveled off.

Three weeks later, when tutoring was introduced for Dancer 11, her degree of anterior tilt decreased from a mean of 16° to a mean of 12°. All eight assessments of pelvic tilt following the introduction of tutoring were lower than any of the seven assessments made during baseline. The measurement of anterior tilt for Dancer 15, who had not yet received tutoring, stabilized between 13° and 15°.

When Dancer 15 finally received the tutoring intervention, she, like the two dancers before her, decreased her anterior pelvic tilt from a baseline mean of 14° to a mean of 11° during tutoring, with only one session overlapping the lowest measurements recorded during baseline.

For all three dancers, distinct reductions in anterior tilt occurred *every time* the tutoring intervention was applied, which suggests that tutoring, and not other uncontrolled variables, was responsible for the

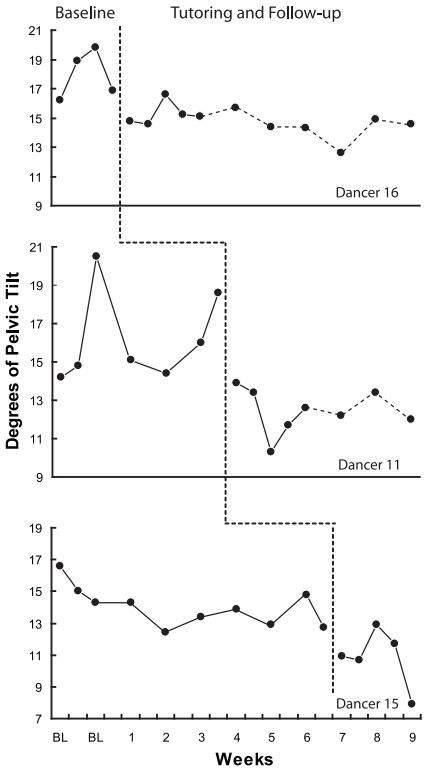

Figure 3 Anterior pelvic tilt before, during, and following tutoring for all three dancers who received tutoring. Dashed vertical lines show the initiation of tutoring for each dancer. Data points connected with dashed lines were gathered after tutoring ended.

changes in alignment. Even Dancer 15, who reduced her anterior tilt early in baseline, made greater gains when she received tutoring six weeks later. In addition, once alignment improved for each dancer, the improvement was sustained, even after tutoring had concluded for Dancers 16 and 11. On average, the dancers reduced their degree of anterior pelvic tilt by 3.3°.

The social validity questionnaires revealed a top rating of 5 for the importance of good pelvic alignment, and a rating of 4.6 for the contribution of tutoring to alignment improvement. All three dancers mentioned the benefits of focusing on specific problem areas and asserted that tutoring was a very good use of their time that had increased their awareness and understanding of neutral pelvic alignment.

Preliminary interviews indicated that pelvic misalignment was a problem the dancers were very aware of, but had been unable to correct with regular ballet classes. Their responses to the questionnaire support the desirability of employing an individualized approach. The results from this study show that an individualized tutoring intervention can produce alignment improvements that are meaningful and important to dancers in a relatively short period of time. In addition, the dancers were able to maintain this improved alignment after tutoring ended.

Changes in alignment occurred soon after the onset of the intervention, which suggests that the changes in alignment probably resulted from improved awareness, muscle recruitment and motor control, rather than from what is traditionally classified as gains in strength or flexibility.[7,18] It may be that continued use of the new alignment would produce changes that could be classified as gains in strength and flexibility, but this question was not addressed in this study. Also, while the dancers' casual reports during tutoring suggested they were rehearsing their new alignment skills and exercises on a daily basis, we did not collect data on the amount of time each dancer spent working on their alignment outside the tutoring sessions. Both issues might be addressed in future research.

The results of Experiment 3 suggest that dancers who arrive at a university dance program with problematic pelvic alignment can improve their alignment with as little as six hours of individual tutoring.

General Discussion

These studies were designed to assess pelvic alignment for 17 first-year dancers, the degree of pelvic tilt acceptable to their university ballet instructors, and the effects of tutoring on three dancers who displayed excessive anterior pelvic tilt. Experiment 1 used repeated measurements to reveal substantial day-to-day variability between and within dancers, which is consistent with previous research.[5,7] It also showed a high incidence of anterior pelvic tilt among the 17 participants. Experiment 2 revealed that a mean of 11° of anterior tilt was judged to be acceptable pelvic alignment by ballet teachers. Seventy percent of first-year dancers who participated in this study displayed a mean degree of anterior tilt that was greater than the acceptable mean. Experiment 3 showed that with individual tutoring involving strengthening, stretching, and awareness exercises, dancers were able to substantially improve their pelvic alignment.

Three limitations of these studies should be addressed. First, the tutoring intervention evaluated in Experiment 3 consisted of a collection of variables that were analyzed as a package. While the experimental analysis shows that the intervention, as a whole, was responsible for the change in performance, it is possible that some of the components of the intervention were unnecessary. Future research might analyze the relative contribution of each component of the tutoring intervention with the aim of creating a more efficient training strategy. Second, because our analysis of pelvic alignment focused only on the sagittal plane, it cannot account for alignment fluctuations that may have occurred on other planes of movement. Similar analyses of frontal and transverse plane alignment might be undertaken in future research to determine if comparable improvements can be achieved on other planes of motion. Finally, the experimenter used palpation to place reflective markers on the dancers' anterior and posterior superior iliac spines. This placement method was simple, noninvasive, and the current standard for similar research in the field. We were, however, unable to devise a procedure to assess the reliability of the marker placement. Future research could benefit from the development of procedures for insuring the reliable placement of reflective markers.

We used a within-subject research design in Experiment 3 to demonstrate experimental control of the dependent variable by the independent variable.[19] By repeatedly measuring pelvic alignment before, during, and after tutoring, direct and continuous observation of the effects of tutoring was possible. Changes in pelvic tilt were determined by comparing baseline measurements to post-intervention measurements, subject-by-subject. A within-subject analysis has two major advantages for an experiment of this type.[5,16] First, it allowed the experimenter to work intensively with a few dancers and tailor the intervention to each dancer's individual needs, a feature that was rated highly by the dancers in the post-intervention questionnaire. Second, by not averaging results across dancers, variation in individual performance was directly observable. Readers can directly assess individual variability in Figure 3 to determine its possible influence on the demonstration of experimental control, without having to rely on post-hoc, statistical testing. We encourage other dance researchers to consider the use of within-subject experimental designs, especially when the goal of an intervention is to improve individual performance in elite performers.

In conclusion, excessive anterior pelvic tilt may be a relatively common and chronic misalignment among preprofessional ballet dancers. Individual tutoring appears to be one method

for improving pelvic alignment in student dancers who have not been successful in addressing the problem in their technique classes. Future studies might address the potential benefit of incorporating elements of the tutoring procedure directly into dance technique classes.

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