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Pedobarographic and Musculoskeletal Examination of Collegiate Dancers in Relevé

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ABSTRACT

Twenty-one collegiate ballet pupils were evaluated via history/questionnaire, musculoskeletal assessment, and pedobarographs, focusing on factors (e.g., alignment of hip, knee, and foot) thought to affect the important and common second-position relevé in dance. In a blinded manner, three observers classified the pedobarographs (obtained by an independent examiner) according to force distribution through the foot. Most dancers bore weight through the toes and transmitted force on both the medial and central metatarsal heads, and some transmitted force through only one of these rays, but none transmitted force through the lateral ray alone. This analysis provides a baseline for future assessment of normal or abnormal dance maneuvers.

Key Words: Pedobarographs, Ballet, Second-Position Relevé, Weight Transfer, Alignment, Force Distribution

INTRODUCTION

Dance screening programs dependent on cooperation among the ballet instructor, physiotherapist, and orthopaedist[5] have been developed in several centers. The current musculoskeletal assessment involves observing each dancer as he or she moves through a number of positions and exercises. The goal of the assessment is to define the functional range of limb and joint position as well as muscle balance and weight distribution for each particular dancer, thus identifying the dancer's limitations secondary to musculoskeletal anatomy or physiology rather than technical errors.[5] Such assessment often identifies previously unrecognized injuries; this information is then used to develop safe and aesthetic compensatory techniques in an effort to prevent further acute or chronic injury by working within the individual dancer's range of function.[5]

Pedobarograph examination is not part of the assessment process because the equipment is stationary and the sessions are usually held at a dance studio. The pedobarograph allows the pattern of weight distribution on the sole of the foot to be studied in detail, providing both static and dynamic data that facilitate comparison

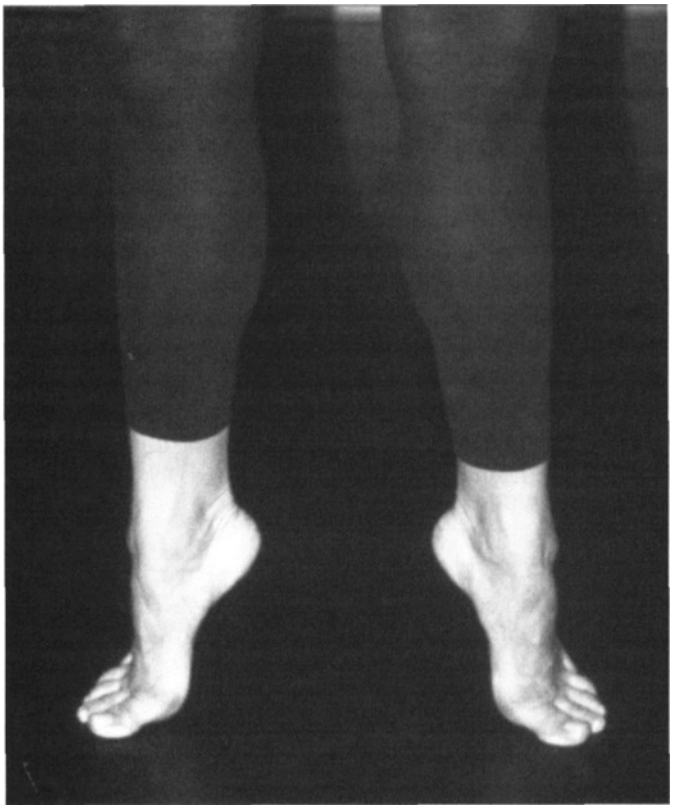

Fig. 1: Relevé to demi-pointe. The ankle is maximally plantarflexed and weightbearing (WB) is on the toes and metatarsal heads.

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Fig. 2: Radiographic evaluation of relevé to demi-pointe. The metatarsophalangeal joints are dorsiflexed and the metatarsals are collinear with the tibia.

with the clinical impression of force distribution of the foot. The pedobarograph quantifies the weightbearing, determines the center of pressure (P_{cent}), and identifies maximum pressure (P_{max}).

In the relevé maneuver, the dancer moves the feet into the first position by pivoting on the heels and externally rotating the feet. The feet are then separated from one another while the dancer maintains his or her externally rotated position (second position). Next, the dancer rises onto the metatarsal heads with the ankle maximally plantarflexed and the toes dorsiflexed at the metatarsophalangeal (MTP) joints (Fig. 1). Ideally, the dancer balances in this position with the legs axially aligned with the feet (Fig. 2). "Placement" or proper orientation is typically felt to be determined by learned technique, strength, mobility, balance, and structural or anatomic factors in the lower extremity.[1,2,4,5] We wanted to develop a better understanding of the normal distribution of pressures in relevé from second position to demi-pointe based on musculoskeletal history, physical examination, dancer self-assessment, and pedobarographic assessment. Correlation of weightbearing patterns to a multitude of identified factors could provide insight into normal and abnormal relevé.

MATERIALS AND METHODS

Twenty-one collegiate dance students (20 women, one man) were evaluated. Their average age was 20 years (range, 18 to 22 years), and they spent an average of 10 hours (range, four to 20 hours) a week dancing and had been studying dance for an average of 11 years (range, four to 18 years). Their evaluation was performed by an eight-member dancer assessment team composed of the senior author (LCS), two orthopedic foot and ankle fellows, a physical therapist specializing in dance, two dance instructors, and two other dancers trained in physical assessment. Each dancer completed a self-assessment form. The questionnaire and musculoskeletal evaluation yielded data on demographics, alignment, mobility, and strength as well as a dynamic assessment of each dancer in nine positions: the five classical positions, relevé, demi-plié, plié, and développé á la seconde. During relevé, special focus was placed on lower extremity alignment and metatarsal and toe contact with the floor. Alignment was assessed in the sagittal and coronal planes. The coronal plane and the line of the anterior tibial border and the tibial tubercle were compared with the line of the second metatarsal and the center of the navicular. In the sagittal plane, the line of the anterior tibial shaft was noted relative to the dorsum of the foot. For each dancer, three or more observers participated in the determination of these measurements.

Relevé position was chosen because it is a position required in almost every dance movement. In relevé, the ankle is plantarflexed, the toes are dorsiflexed, and stress is focused in the metatarsal heads. In this investigation the focus was the relevé from second position into the demi-pointe position.

At three to nine months after this assessment, an independent tester (JH), who was blinded to the original assessment, performed a pedobarographic analysis of the relevé. The independent tester instructed the dancers in a uniform fashion, requesting each dancer to assume second position (as in dance class) with the right foot on and the left foot off the pedobarograph. The dancer indicated when proper placement had been achieved and a pedobarograph was taken of the right foot in this flat position. Next, each dancer was instructed to perform a relevé to the demi-pointe position (as in dance class) and, again, to indicate when proper balance was achieved. At this point, a second pedobarograph was taken of the foot. The independent tester maintained eye contact with each dancer; at no time did she look at the computer screen or the dancer's feet.

For each dancer, this routine was repeated to obtain a second set of pedobarographs. If the two sets of pedobarographs varied, a third set was obtained in the same manner to exclude an atypical result. (This occurred in only three dancers.) A fourth test to clarify additional inconsistencies was not required. No dancer was informed about the pedobarographic results during the session and there was no comparison of the results with any previously collected data.

Assessment of the data was performed by the three orthopaedists and a dance-science undergraduate. The computer printouts of the pedobarographs were displayed and determinations were made of toe contact, metatarsal weightbearing distribution, P_{max} points, and the P_{cent} as provided by the computer analysis. To

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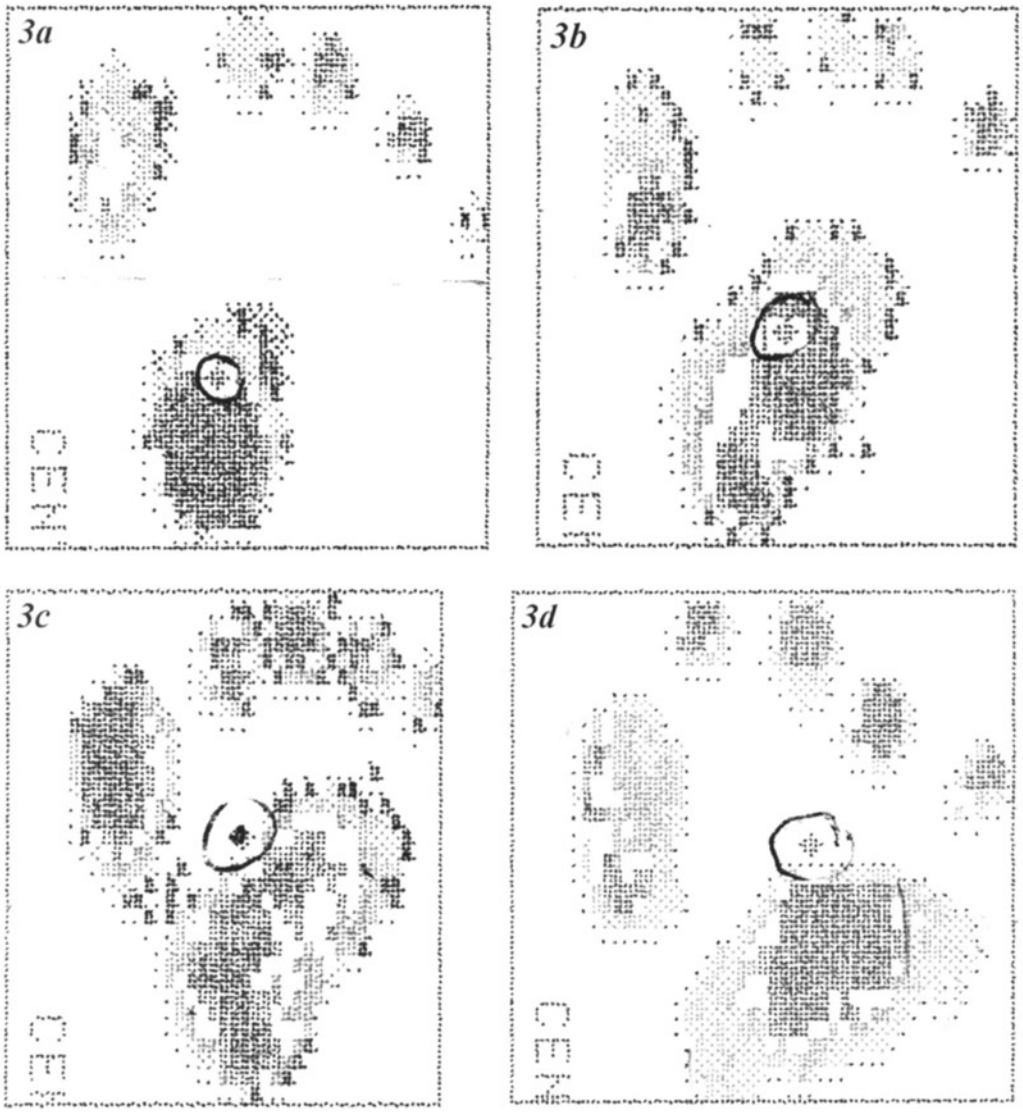

Fig. 3a *(top left)*: Pedobarographic example of relevé with WB on all toes, showing WB on the first and second metatarsals, P_{cent} on the first web space, and P_{max} on the first metatarsal. **Fig. 3b** *(top right)*: Pedobarographic example of relevé with WB on all toes, showing WB on the first, second, and third metatarsals, P_{cent} on the second metatarsal, and P_{max} pressure on the first and second metatarsals. **Fig. 3c** *(bottom left)*: Pedobarographic example of relevé with WB on all toes, showing WB on the first through the fourth metatarsals, the P_{cent} on the second metatarsal, and P_{max} pressure on the first through the third metatarsals. **Fig. 3d** *(bottom right)*: Pedobarographic example of relevé with WB on all toes, showing WB on the first through the fourth metatarsals, the P_{cent} on the third metatarsal, and P_{max} on the second through the fourth metatarsals.

facilitate interpretation of the dancers' pedobarographs in the relevé position, we devised a method of systematic analysis. The analysis permits description of the weightbearing characteristics of the metatarsal heads and the phalanges and their interaction.

The number and position of the phalanges bearing weight was recorded. The focal point of hallux loading, if present, was then recorded as interphalangeal or distal phalangeal, based on the focus of pressure and its relation to the pressure imprint of the metatarsal heads. Based on the appearance of the pressure imprint, the pattern of weightbearing pressure exerted on the metatarsal heads was categorized in terms of the area where pressure was exerted predominantly:

1. on one or two metatarsal heads (Fig. 3a);
2. on three metatarsal heads (Fig. 3b); or
3. on four or five metatarsal heads (Fig. 3c, d). The pressure distribution for weightbearing of the metatarsal head was then further characterized as dominant in either the medial (first, second, and third metatarsals), central (second, third, and fourth metatarsals), or lateral (third, fourth, and fifth metatarsals) region, based on the P_{max}.

For instance, if the P_{max} was over the first and second metatarsals, the pressure distribution was considered medial dominant. Similarly, the pressure distribution of weightbearing in the phalanges was considered as medial, central, or laterally dominant.

Once the pressure distributions of the metatarsal head and phalanges were characterized, they were combined to produce a weightbearing axis, classified as medial, if weightbearing was predominantly borne by the central or medial aspect of the metatarsal head and the medial phalanges; central, if the weightbearing aspect passed form the medial or central aspect of the metatarsal head to the central phalanges; lateral, if the weightbearing passed from central or lateral aspect of the metatarsal head to the lateral phalanges; or tripodal, if the metatarsal head dominance was medial or central and

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Table 1: Assessment Factors

Category	Factor
Pedobarographic	Metatarsal weightbearing pattern
	Toe weightbearing
	P_{cent}
	P_{max}
	Metatarsal weightbearing distribution
Musculoskeletal	Plié
	Relevé MTP dorsiflexion
	Internal and external rotation of the hip
	Metatarsal weightbearing distribution in relevé
	Degree of turnout of the feet
Self-assessment	Metatarsal weightbearing distribution in relevé
	Foot/ankle positioning
	Rolling in
	Rolling out

pressure was equally distributed between the lateral and medial phalanges. Finally, the pressure distribution between the metatarsal head and the phalanges was determined to be either metatarsal-dominant, if the P_{cent} was within the metatarsal foot print; phalangeal-dominant, if the P_{cent} was outside the outline of the metatarsal print; or nondominant (shared or balanced) (Fig. 3d).

All results from the questionnaires, musculoskeletal assessments, and pedobarographic analyses were entered into a database using the SPSS Program (SPSS Inc., Chicago, IL). We compared the following:

1. the clinical determination of relevé metatarsal-loading pattern and the metatarsal distribution on pedobarograph (P_{max}, P_{cent}, and metatarsal weightbearing);
2. the metatarsal distribution in relevé (P_{cent}, P_{max}, and metatarsal weightbearing), the dancer's self-assessment of foot and ankle position (rolling in or rolling out), and their self-assessed metatarsal loading pattern;
3. decreased range of motion of the first MTP joint (<90°), and the metatarsal weightbearing distribution, the P_{cent}, and P_{max} during relevé; and
4. hip rotation and turnout and P_{max}, P_{cent}, and metatarsal weightbearing (Table 1).

RESULTS

Self-Assessment

Dancers studied ballet for an average of 11 years (range, seven to 18 years), jazz for an average of seven years (range, one to 12 years) , and modern dance for an average of four years (range, one to 13 years). The mean number of years en pointe was 7 (range, five to 18 years). Four dancers felt they rolled in from the central axis and three dancers felt they rolled out. Most dancers (12/21) felt they were weight-bearing on the first through third metatarsals during relevé to demi-pointe.

Musculoskeletal Assessment

Of the eight dancers with <90° of first MTP dorsiflexion, seven loaded underneath the first metatarsal head. Of the 13 dancers with 90° or more of first MTP dorsiflexion, 10 loaded under their first metatarsal head.

The average turnout of the feet was 47° (range, 27-60°). Of the five dancers with decreased hip external rotation, four had less than 47° (range, 2.7 to 46.5°) and one had 60° of turnout. Of the seven dancers with increased external rotation, four had more than 47° of turnout. Twelve dancers had either increased or decreased external rotation.

Coronal alignment of the tibial crest was medial to the second metatarsal in four dancers, at the second metatarsal in 15, and lateral to the second metatarsal in two. Sagittal alignment of the tibial crest relative to the dorsum of the foot was 180° or collinear in 16 dancers, less than collinear in two, and beyond collinear in three (i.e., the foot was more plantarflexed than the line of the tibia). In relevé, the 21 dancers had the following metatarsal weightbearing patterns: first to second (4/21), first to third (9/21), first to fourth (6/21), second and third (1/21), and first to fifth (1/21).

Pedobarographic Assessment

There were only three pedobarographic trials in which three readings were necessary. The pattern of metatarsal weightbearing in the relevé position was rhomboid-shaped in 9/21 dancers (43%), kidney-shaped in 8/21 (38%), and ovoid in 4/21 (19%). The dominant pattern of metatarsal loading was central in 10/21 (48%), medial in 10/21 (48%), and lateral in 1/21 (5%).

Of the 21 dancers, 15 (71%) loaded all five phalanges during relevé, two loaded the medial four phalanges, and one loaded the medial three phalanges (Table 2). Only one dancer did not load the hallux; she loaded the lateral four phalanges. Two dancers did not load the second and third phalanges. The dominant pattern of phalangeal loading was central in 10/21 (48%), medial in 6/21 (29%), and lateral in 5/21 (24%).

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Table 2: Pedobarographic Results of 21 Dancers

Location	Metatarsal Weightbearing	P_{cent}	P_{max}
1st metatarsal			4
1st web		4	
1st & 2nd metatarsal	1		3
1st → 3rd metatarsal	7		6
1st → 4th metatarsal	10		2
1st → 5th metatarsal	1		
2nd metatarsal		6	
2nd web		8	
2nd & 3rd metatarsal			1
2nd → 4th metatarsal	2		4
3rd metatarsal		3	1

Of the 20 dancers who bore weight on the hallux, 15 (75%) loaded the distal phalanx, four (20%) loaded the interphalangeal region, and one (5%) loaded both areas of the hallux.

The weightbearing axis from the metatarsal to the phalanges was characterized as tripodal in 8/21 (38%), medial in 7/21 (33%), lateral in 4/21 (19%), and central in 2/21 (10%). Weightbearing was predominantly borne by the metatarsals in 15/21 (71%), shared by the metatarsals and phalanges in 5/21 (29%), and borne more by the phalanges in 1/21 (5%).

In the foot flat second position, it was interesting to note that the P_{cent} was on the heel quadrant in 10/21 and more centrally located between the metatarsals and the heel in 11/21.

Comparisons

Musculoskeletal, pedobarographic, and self-determined assessments of metatarsal weightbearing in relevé were compared. The musculoskeletal evaluations and pedobarographic assessments showed agreement in 9/21 dancers, a difference of one metatarsal in 7/21 dancers, a difference of two metatarsals in 7/21 dancers, and a difference of three metatarsals in 1/21 dancers. Regarding metatarsal weightbearing in relevé, the dancer's self-assessment and the pedobarographic evaluation agreed in only two cases, and musculoskeletal assessment and the dancer's self-assessment agreed in only three cases.

Surprisingly, five of the eight dancers with <90° of dorsiflexion of the first MTP joint loaded the hallux and the first metatarsal head according to the pedobarograph; the other three loaded the lateral metatarsal heads and had increased pressure on the first phalanx, but not its metatarsal head. Of the 13 dancers who had ≥90° of dorsiflexion of the first MTP joint, 10 loaded the metatarsal head as well as the first phalanx.

There was no relationship between turnout and the weightbearing distribution on the metatarsal heads or of the P_{cent} in metatarsal contact in développé á la seconde. Similarly, dancers who felt that they had a tendency to deviate from the central axis during metatarsal contact in relevé (rolling in or out) did not show any pattern of variation on the pedobarograph assessment.

DISCUSSION

It is generally thought that good dance form is derived from a combination of inherent anatomic structure (including strength and flexibility) and adherence to proper technique. The current study of collegiate-level dancers has shown a wide range of pressure distribution patterns. The pedobarograph proved to be a sensitive device, revealing differences in weightbearing characteristics in this population when trained instructors, therapists, and orthopaedists observed only minor technical deviations. This finding highlights the weakness of visual observation alone in identifying subtle mechanical abnormalities that can predispose to overuse injuries.

The dancer's self-assessment of alignment and force distribution during the relevé was poorly associated with pedobarographic and musculoskeletal assessment results. This points to a surprisingly limited specific anatomic awareness despite the many hours spent dancing and developing dance techniques. This view is reinforced by the incorrect technique of 10 of 21 dancers in the flatfoot second position, in which the P_{cent} was in the hindfoot rather than forward, as classically taught.

In no case did the degree of turnout or hip movement show an association with abnormalities of foot force transfer detected in either the musculoskeletal or pedobarographic examination process. This is an unusual finding because turnout is one of the most emphasized positions in classical ballet.[2,4] We postulate that the annual dance screening program has resulted in heightened awareness among staff and students of problems associated with forced turnout. In this program, this awareness has nearly eliminated the problem of "screwing" the knee and foot to improve turnout, at least during a musculoskeletal evaluation. This fact, reflected in the relatively low turnout angle and the absence of forced turnout noted in this population, would explain the poor association of foot abnormalities with degree of turnout.

Limited motion of the first MTP joint resulted in alteration in the loading pattern of the foot in only three of seven dancers; four of the seven had essentially normal force patterns. In the three with altered patterns, the result was esthetically acceptable in that the dancers simply compensated by increasing force transmission

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through the hallux and lesser metatarsal heads, which resulted in little change in overall foot alignment.

The pedobarograph is easier to perform accurately than is a musculoskeletal assessment. When not using the pedobarograph, the observer must bring his or her eyes close to the ground, palpate the metatarsals while the dancer is positioned, or slide a piece of paper under the metatarsals to determine which portion is in contact with the ground. This process forces the dancer to hold the position and alters the actual event, unlike the instant reading with the pedobarograph. With the pedobarograph, stance balance and positioning better reflects the dancer's norm because it is less likely that the dancer will combine proprioception with the visual and other feedback that is inevitable during a physical examination as the position is held. The pedobarograph's greatest disadvantages are its limited availability and the cost of the equipment.

The real utility of this device may be not in assessing a normal, asymptomatic population, but in helping to determine the cause of overuse pathology. Unlike the diagnosis of acute trauma, for which there is clear causation and identifiable physical signs, the diagnosis of an overuse injury is more challenging, especially in a dancer complaining of nonspecific foot pain.

In clinical practice, it is difficult to obtain a pedobarographic evaluation. The studies will be most illuminating in patients with pathologic forefoot conditions that are not grossly apparent, such as subtle metatarsal imbalance or dynamic imbalance. The issue of implications for retraining is an interesting question. Concurrent feedback of post-activity movements can be very helpful in neuromotor assessment or movement education.[3,6,7] Whether this tool could be used to enhance a dancer's performance remains to be tested. Future studies could consider whether the use of pedobarographic data by dancers could help them achieve increased self-awareness of movement, but this improved self-awareness may not necessarily correlate with improved performance as a dancer.

In summary, in this group of collegiate dancers, pedobarographic analysis provided insight into the weightbearing patterns on the toes and metatarsals. Most dancers bore weight on all the toes and on the first to the third metatarsal heads. The P_{cent} was typically at the second metatarsal. The pedobarographic analysis was more closely associated with the musculoskeletal assessment than with the dancer's self-assessment. Interestingly, there was no association between musculoskeletal histories or conditions and any weightbearing pattern. Because strength, range of motion, and structural factors did not seem to determine the forefoot pressures, we found technique and balance played a major role. This analysis of normal mechanics for this group of dancers provides a baseline for future assessment of normal and abnormal dance maneuvers.

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