Article

# Effects of Dancer-Specific Biomechanics on Adolescent Ballet Dancers' Posture En Pointe and Factors Related to Pointe Readiness

## A Cross-Sectional Study

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**OBJECTIVE:** There are no universally accepted requirements or uniform protocols to determine when dancers can safely commence dancing *en pointe* (shod *relevé*). The purpose of this study was to examine dancer-specific biomechanics of adolescent pointe dancers and explore factors that may help determine pointe readiness. **METHODS:** Dancers (n=26; median age 14 yrs [IQR=13–16]) were stratified into two groups based on the ability to stand on the pointe shoe box as per a plumb line (Group 1: on the box; Group 2: not on the box) during parallel, shod *relevé*. Measurements included unshod weight-bearing range of motion (ROM) of ankle plantarflexion (PF) and first metatarsophalangeal (MTP) extension and shod posture assessment during first position *elevé* (rising into *relevé* with turned out, straight legs). Qualisys™ 3D motion capture and AMTI™ force plates recorded dancers performing 10-15 repetitions of first position *elevé*. Comparison of three kinematic and three kinetic variables aimed to describe group differences during unshod and shod conditions. Wilcoxon signed-rank test assumed no difference between groups with a Bonferroni correction ($p<0.0083$). **RESULTS:** During unshod parallel *relevé*, ROM was different between groups for first MTP extension (deg; $Med_{Group1}$: 90°, IQR 80°–90°; $Med_{Group\ 2}$: 70°, IQR: 70°–80°, $p<0.0001$) but no statistical difference in ankle PF (deg; $p=0.0098$). There were no differences in C7 displacement (m; $p=0.5055$), ankle PF moment ($p=0.1484$), or hip mediolateral and anteroposterior moments ($p=0.8785$ and 0.8785, respectively) during shod first position *relevé*, indicating that both groups tend to engage the same dominant muscle groups (trunk extensors, ankle dorsiflexors, hip flexors, and hip abductors) during *elevé*. **CONCLUSION:** Dancers in Group 1 demonstrated greater first MTP extension during unshod *relevé* compared to dancers in Group 2. Weight-bearing ROM could be a valuable tool in predicting pointe readiness of adolescent ballet dancers. *Med Probl Perform Art* 2023;38(3):155–163.

**KEYWORDS:** dance, ballet, biomechanics, first metatarsophalangeal joint, pointe readiness, posture

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**INVESTIGATORS** concur that most injuries involving adolescent ballet dancers develop when the average dancer commences pointe work, typically between 11 and 12 years.[1-4] This raises safety concerns within the field of dance medicine, particularly for young dancers during critical skeletal development.[5,6] In response to these concerns, many clinicians and researchers focus on developing protocols using various tests and measures when screening their dancers for pointe readiness.[3,4,7-12] Yet, there are no universally accepted requirements or uniform protocols to determine when female dancers can safely commence dancing *en pointe* (standing on the toes in pointe shoes with maximum flexion of the ankle joint and toes in a neutral position relative to the long axis of the foot[13]).[11,12]

Many tests and measures reportedly used for pre-pointe screenings are those commonly assessed during pre-season dance screens, including functional balance tests (e.g., air-plane and Star Excursion Balance Test), mobility (e.g., Beighton scale), flexibility (e.g., hamstring length), range of motion (ROM; e.g., hip rotation, ankle plantarflexion [PF] and dorsiflexion [DF], first metatarsophalangeal [MTP] extension), strength and endurance (e.g., flexor hallucis longus [FHL], core stability, ankle plantarflexors), and dance-specific technique assessments.[2,3,8-12,14-16] However, they have yet to be validated for determining pointe readiness using cohorts of adolescent dancers either in the pre-pointe training phase or those novice to pointe dancing.[11]

When ballet dancers begin dancing *en pointe*, they must learn how to transition from balancing on the metatarsal heads in demi-pointe *relevé* (standing on the balls of the feet with the ankle in maximum plantarflexion with toes extended) to the toes. Imagery studies using MRI[17] and radiography[18] of dancers *en pointe* illustrate how the talus's anterior surface becomes the ankle's primary weight bearing site. The change in center of gravity (COG) and reduced base of support (BOS) when novice dancers learn to balance *en pointe* requires relearning numerous dance movements.[19] This COG shift also causes balance control and postural stability changes at the hip and trunk.[20] The process of learning how to "center" the body over the supporting leg(s) with a stable, fully plantarflexed ankle, from the balls of the feet (the metatarsal heads) to the tips of the toes while maintaining an upright posture[21,22] put the novice dancer at greater risk of injury[21,23,24] when they are first learning to dance in pointe shoes.

Pointe shoe construction includes a toe box (layers of burlap, cardboard, and paper glued together to form the standing platform and the vamp), shank (the shoe's insole made of cardboard, leather, or a combination thereof), and satin covering.[25] Dancers stand on the platform of the toe box and require support from the shank when *en pointe*.[25] When axially loaded in the *en pointe* position, the bones and soft tissues of the foot and toes must work with the mechanical properties of the pointe shoe to absorb some of the ground reaction forces transferred into the body.[24-26] This necessitates the pointe shoe, foot, and ankle to function together as a strong and stable unit to create a load-sharing environment for sound biomechanics when *en pointe*.[25,26] Biomechanical and kinematic factors of unshod dancers in demi-pointe *relevé*,[20,23,24,27-29] and examination of the ranges of ankle motion exerted by the ballet dancer[17,18,20,23,24,28,29] are well-defined in the literature. However, there is limited evidence of the biomechanics and kinematics of dancers *en pointe*,[14,17,30-35] with few studies specifically related to the adolescent pointe dancer.[11,12,20,36]

Ballet dancers must have sufficient ankle and foot ROM during dance-specific movements,[27,31,35,37] to balance with postural stability. Investigators have used various protocols and instruments to measure the ankle and foot ROM, with the MTP joint being the most examined segment of the foot complex. Rowley et al.,[38] measured maximum MTP extension with the dancer weight bearing through the ball of the foot while seated in a chair using a goniometer (mean=101.95°±8.4). Jarvis and Kulig[23] measured first MTP joint extension during *relevé* in second position (legs turned out or externally rotated with hips abducted just past the width of the pelvis) using a Qualisys™ 3-dimensional (3D) motion capture system (mean=54.3°± 4.0). Wiesler et al.[39] measured non-weight bearing (NWB) first MTP joint extension seated with a standard goniometer ($mean_{Left}$=54.5°±1.4; $mean_{Right}$ =55.2°±1.3). Other authors anecdotally define "90 degrees" as the necessary or approximate amount of ROM required at the first MTP joint.[23,27] A description of how much ROM is necessary for the novice dancer to safely transition to dancing *en pointe* with good postural alignment and the ramifications of having decreased ROM remains unknown.[1,39] This description is necessary to examine how limited foot ROM may contribute to injuries among adolescent ballet dancers *en pointe*.

Wiesler et al.[39] provided evidence of an association between postural alignment during *relevé* and lower leg ROM among female ballet dancers (age range 12 to 28 yrs). They observed that dancers with greater ankle PF ROM required greater first MTP joint DF (MTP extension) ROM to assume *relevé* over their COG.[39] In full demi-pointe *relevé* (bodyweight centered over the forefoot), the ankle and forefoot are in maximum, opposing ranges of motion. This position places undue stress and strain on the soft tissues of the foot ankle, such as the FHL musculotendinous unit,[38] which likely increases as the dancer transition from *demi-pointe* to *en pointe*. Several studies evaluated ankle[28] and first MTP joint moment patterns[23,40] during dance-specific movement of ballet dancers to measure the rate of change in the angular momentum (torque) and document the demand placed on the ankle and MTP joints. Faulty postural alignment occurs when the dancer's body weight is not centered over the standing leg; yet, few studies compared postural stability during demi-pointe and *en pointe relevé*[32,35] or considered contributions of more proximal segments, such as the hip joint and the trunk, when describing their postural control.[20] Describing the kinetic and kinematic differences between dancers, specifically young dancers, who can center their body weight with an erect trunk and assume a full, upright position on the box of the pointe shoe, and those who cannot may help explain key factors related to pointe readiness.

The purpose of this study was to examine dancer-specific biomechanics and postural stability of adolescent pointe dancers and explore factors that may help to determine pointe readiness. Specific Aim 1 compared the amount of ankle PF and MTP extension ROM (deg) of dancers who get onto the pointe shoe toe box (Group 1) with those who do not get onto the pointe shoe toe box (Group 2). We operationally defined standing "on the box" as a *relevé en pointe* where the platform of the pointe shoes' toe box is parallel with the floor with the toes in neutral, the ankle in full plantarflexion, and parallel alignment of the ankle joint, tibia, patella, and hip center, straight knees, and erect trunk (Fig. 1). Specific Aim 2 compared the position and variability between groups of the net joint

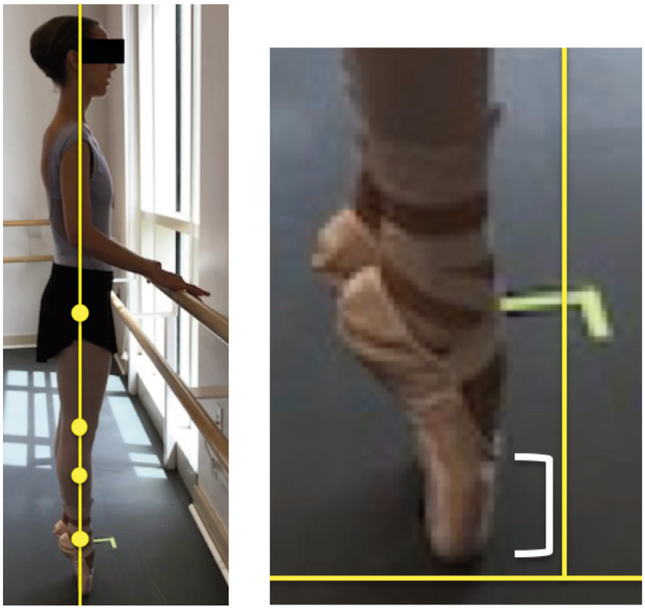

**FIGURE 1.** Plumb line with a dancer "on the box."

moment at the hip and ankle and upright posture at peak *relevé en pointe* in first position using 3D motion capture. We assumed a null hypothesis of no difference between groups.

## METHODS

### Experimental Procedure

Data collection for this descriptive, cross-sectional study took approximately two hours per participant (n=26). The Institutional Review Board of the University of Oklahoma for Health Sciences (#9252) approved this study before recruitment and protocol commencement. All participants underwent formal consent for the protection of human subjects, including parental consent for all participants under 18 years and a statement of assent from those 12 to 17 years. Participant screening prior to data collection ensured they met the pre-determined inclusion criteria (female ballet dancer 12–18 years old, dancing *en pointe* for at least 6 months, no current injuries limiting her from rising onto the *en pointe* position, able to raise *en pointe* with only the index and middle fingers lightly touching the ballet *barré*, and English-speaking). We excluded dancers who were not yet *en pointe*, reported chronic injury or past surgical history to the forefoot that resulted in fusion of the first MTP joint, unable to independently give formal consent or assent (children under 12 years of age), and danced professionally. The study excluded males as men typically do not dance *en pointe*.[26]

Each participant completed a demographic and history form to include demographics (sex, age, current dance school, pointe shoe type, age they started dancing, and the number of years *en pointe*) and medical information (current health status, medications, and past medical history including dance-related and non-dance-related injuries, and surgeries). Baseline measurements included height (m), weight (kg), baseline heart rate (bpm), baseline blood pressure, generalized or specific pain level on the Wong-Baker FACES® Pain Rating Scale,[41] and a posture screen. The first author, a licensed physical therapist with over 20 years of clinical experience, evaluated foot and ankle ROM, joint mobility, and manual muscle testing). Goniometric measurements of the ankle and hallux in weight bearing (WB) and NWB were replicated from a previous pilot study that utilized the same data collection protocol for elite ballet dancers.[35,42] When measuring ankle PF, the proximal and distal arms of the goniometer were aligned along the shaft of the tibia and the first MTP joint, respectively, with the medial malleolus as the fulcrum point. When measuring first MTP joint extension, the proximal and distal arms of the goniometer were aligned along the medial midline of the first metatarsal and phalanges, respectively, with the axis at the first MTP joint.[38] These alignments intend to measure full ankle and foot complex sagittal plane ROM and replicate the marker placement of the ankle and hallux segments created through 3D motion capture.[35,42]

The first author grouped each dancer as either "on the box" (Group 1; n=11) or "not on the box" (Group 2; n=15) when assuming the *en pointe* position with the feet in parallel using visual observation (Figs. 1 and 2). Placement into Group 2 occurred if any of the abovementioned components aligned anteriorly or posteriorly to the imaginary plumb line (Fig. 2d). The first author confirmed group assignment during raw data processing in Qualisys™ by evaluating the alignment of specific segment markers (Figs. 2b and 2d, stick-figure schematics) and further confirmed grouping when observing data collection trials in first position *elevé*. We blinded dancers to group assignment and the first author to the initial grouping when confirming the final group status. A pilot study in the same laboratory tested a dance-specific modified Rizzoli Foot Model (RFM) used for this study on 11 elite ballet dancers unshod and shod in pointe shoes.[42]

#### *Instruments and Equipment*

A 12-camera Qualisys™ Motion Analysis System (Qualisys, Goteborg, Sweden) recorded 3D kinematic and kinetic data. A digitized procedure captured the 3D coordinates of each reflective marker subsequently used as the basis for calculating segmental joint angles[43] during dance-specific movement. AMTI™ Force plates (AMTI, Watertown, MA) recorded ground reaction forces (GRF) and COP location data at 2,400 Hz. Considering the uniqueness of each dancer's foot structure and shoe preferences, standardizing the pointe shoe is generally not considered feasible or safe for studying dancers *en pointe*.[25,28] Therefore, dancers wore their own pointe shoes for data collection. The first author inspected the pointe shoes to ensure the shank and box were "broken in" but not "broken" or unstable, as described in previous studies investigating

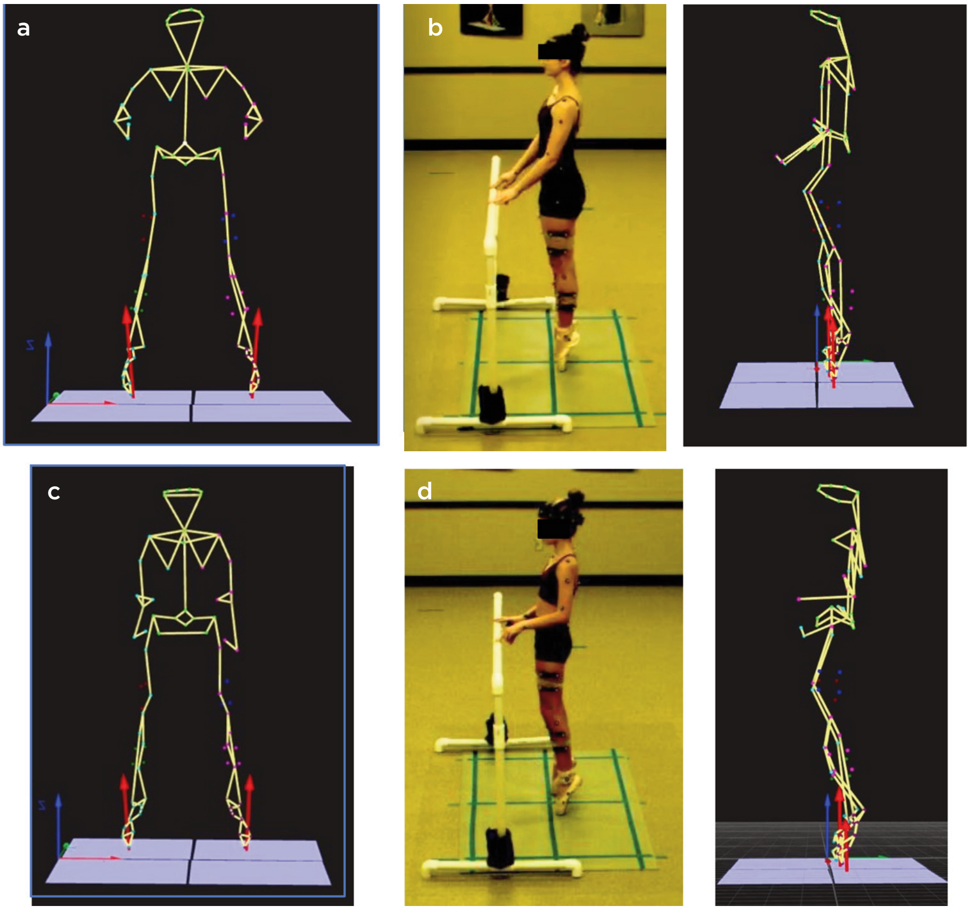


**FIGURE 2.** Images from Qualisys™ (red arrows are ground reaction force arrows from AMTI™ force plates). **a.** *relevé* in first: Group 1 dancer. **b.** *relevé* shod in parallel: Group 1 dancer. **c.** *relevé* in first: Group 2 dancer. **d.** *relevé* shod in parallel: Group 2 dancer. For Group 1: on the box *(relevé en pointe* where the platform of the pointe shoes' toe box is parallel with the floor with the toes in neutral, the ankle in full plantarflexion, and parallel alignment of the ankle joint, tibia, patella, and hip center, straight knees, and erect trunk; aligned with the dancer-specific plumb line). For Group 2: not on the box (*relevé en pointe* where the dancer is not able to stand on the box of the pointe shoe with alignment either anterior or posterior to the dancer-specific plumb line).

pointe shoe deterioration.[26,30] Dancers typically break-in their pointe shoes before dancing in them for improved comfort. Shoes were considered acceptable for data collection if they had a firm shank that maintained rigidity when attempting to bend it and did not buckle when the dancer stood *en pointe* and the toe shoe box was firm.[26,30] Documentation of the shoe included the brand, wear patterns, and stability and length of the shoes' vamp, box, platform, and shank.[25]

### *Movement Trials*

Participants performed a self-selected warm-up for 10 minutes in their pointe shoes at the ballet *barré* before data collection. Dancers traditionally use the ballet *barré* or *barré* as an external support when warming up at the start of the ballet class and for safety when learning new skills,[19] such as dancing *en pointe*, until they build the necessary strength to perform the movements without support. Considering this study involved a cohort of novice dancers, we deemed it was essential for the safety of the participants to use a ballet *barré* for data collection. To ensure continuity, all dancers received the same verbal cues to place their hands on the ballet *barré* using "light touch" for balance and safety[19] while performing 10 to 15 repetitions of *elevé* in first position with their self-selected amount of turn-out. Dancers performed the *elevé* at a rate of 45 bpm on a standard metronome as described in a previous study evaluating dancers during *relevé*.[23] Between movement trials, investigators monitored heart rate, pain level (Wong-Baker FACES® Pain Rating Scale),[41] and perceived exertion (RPE).[44] We removed the reflective markers after data collection and recorded post-trial heart rate, oxygen saturation, blood pressure, and pain level measures.

## Data Processing and Analysis

We conducted data analysis on one lower limb per participant (13 right and 13 left) based on evidence from previous studies that reported high correlation (ICC = 0.99) in ankle movement patterns between the two extremities during

**TABLE 1.** Participant Demographics by Group (n=26)

| | Median | | Q1–Q3 | | IQR | | Wilcoxon Exact test (p-value) |
|---|---|---|---|---|---|---|---|
| | Group 1 | Group 2 | Group 1 | Group 2 | Group 1 | Group 2 | |
| Age (yr) | 15.00 | 14.00 | 14–16 | 13–16 | 2 | 3 | 0.1297 |
| Height (m) | 1.66 | ^1.64 | 1.6–1.7 | 1.6–1.7 | 0.09 | 0.09 | 0.2627 |
| Weight (kg) | 59.60 | 54.43 | 57.6–63.5 | 48.9–58.1 | 5.89 | 9.07 | 0.0326* |
| Age started ballet (yr) | 5.00 | 4.00 | 3–9 | 3–7 | 6 | 4 | 0.4929 |
| Age started pointe (yr) | 12.00 | 11.00 | 11–12 | 10–13 | 1 | 3 | 0.7953 |
| Time in ballet (yr) | 10.00 | 10.00 | 5–12 | 9–10 | 7 | 1 | 0.7453 |
| Time *en pointe* (yr) | 4.00 | 2.00 | 3–4 | 2–2 | 1 | 0 | 0.0202* |

Group 1, on the box (n=11); Group 2, not on the box (n=15). *p < 0.05

*relevé en point*[28] and no statistically significant differences in inter-leg weight bearing distribution during repeated *elevé*[45] among adolescent dancers. We chose the lower extremity with the most robust data capture (defined by full fill of all marker trajectories) during five consecutive *elevé* trials for each participant as the extremity for analysis. Raw data was transferred from Qualisys™ into Visual 3D™ (C-Motion, Inc., Boyds, MD) for filtering and processing. Targets were filtered using a lowpass Butterworth filter with a standard cutoff frequency of 6 Hz. Data were processed using a third-order polynomial interpolation for data loss of up to 10 frames.[46] The 3D biomechanical model for each participant was normalized using body weight (kg) and height (m).

Comparison of six variables, three kinematic (ankle PF and first MTP *relevé* angle [deg] and C7 marker displacement [cm]) and three kinetic (ankle PF, hip mediolateral [ML], and hip anteroposterior [AP] net joint moments [Nm]), aimed to describe between-group differences at the peak *relevé en pointe* position. Balance in the *relevé* position with maximum ankle PF and body weight most centered between the two legs *en pointe* defined the "*peak relevé*" angle (Fig. 2). The first author marked the peak *relevé* event for each repetition in the movement trial for the participants in Qualisys™ using the ground reaction force arrows derived from the AMTI™ force plates. The precise requisite for marking the *in vivo* event occurred when the dancer visually appeared balanced, and the force arrows demonstrated the most symmetry between the LE's before changing position.

To compare the position and variability between groups of upright posture at peak *relevé en pointe* in first position, we used the position of the C7 spinous process relative to the pelvis segment (C7 plumb line[47]). To compare the position and variability between groups of the hip and ankle, we used net joint moment differences at the peak *relevé*. The X-Y-Z rotational sequence defined the hip joint moment pattern as the ML (flexion/extension [flex/ext]), AP (adductor/abductor [add/abd]), and longitudinal (L; external/internal rotation [ER/IR]) components (ML-AP-L).[48] Because the hips maintain a turned out or externally rotated position in first position *relevé*, we only compared the ML and AP components.[48]

## Statistical Analysis

*A priori* power analysis determined that 16 participants (8 per group) were required to achieve 80% power, assuming that dancers "on the box" would have MTP ROM of approximately 90°[27,35] and those "not on the box" would have less mobility. Previous studies indicating that variability of MTP-ROM is between ±4° and ±8°[23,28] formulated the basis of these assumptions. To achieve at least 80% power, investigators recruited 26 volunteers for this study. Initial assessment of the data using Shapiro-Wilks and data histograms indicated that normal distributional assumptions were not valid. Therefore, we used the non-parametric Wilcoxon signed-rank test, assuming a null hypothesis of no difference between groups. We employed a Bonferroni correction for all six comparisons, which adjusted each significance level to 0.0083. This conserved an overall 4.98% chance of a type I error. We computed all statistical tests using SAS 9.4 (Cary, NC). If the calculated p-value of the difference between groups was greater than 0.0083 for each of the six variables, we failed to reject the null hypothesis and concluded no difference between groups.

# RESULTS

Twenty-six participants (median age 14 yrs, median height 1.65 m, median weight 56.93 kg) volunteered to participate from 16 local and regional dance studios (Table 1). While we did not incorporate demographic data into significance testing, Wilcoxon exact test p-values indicate body weight was different between groups at a significance level of 0.05 ($Med_{Group1}$: 59.42 kg, $Med_{Group2}$: 54.43 kg, p = 0.0326). The median weight for Group 1 was greater than Group 2, possibly because Group 1 dancers are slightly, yet not significantly, older than Group 2 dancers ($Med_{Group1}$: 15 y, $Med_{Group2}$: 14 y, p = 0.1297). Time *en pointe* also differed between groups ($Med_{Group1}$: 4 y, $Med_{Group2}$: 2 y, p=0.0202), which is possibly related to the 1-year age difference between groups.

Table 2 includes ROM values and differences between measures of central tendencies (median [med] and interquartile ranges [IQR: Q1-Q3]) by group. For Aim 1, a significant difference between groups in first MTP-ROM at

**TABLE 2.** Measures of Central Tendencies for All Variables: Mean (SD), Median, and IQR by Group (n=26)

| | Median | | Q1–Q3 | | IQR | | Wilcoxon Exact test |
|---|---|---|---|---|---|---|---|
| | Group 1 | Group 2 | Group 1 | Group 2 | Group 1 | Group 2 | (p-value) |
| Ankle PF BF relevé angle (deg) | 168 | 155 | 170–175 | 160–150 | 13 | 10 | 0.0098 |
| First MTP BF *relevé* angle (deg) | 90 | 70 | 80–90 | 70–80 | 10 | 10 | 0.001* |
| C7 displacement (cm) | 0.16 | 0.16 | 0.15–0.17 | 0.13–0.17 | 0.03 | 0.04 | 0.5055 |
| Ankle PF moment (Nm/kg) | 0.08 | 0.13 | 0.04–0.15 | 0.10–0.20 | 0.11 | 0.1 | 0.1484 |
| Hip ML moment (Nm/kg) | 0.13 | 0.15 | 0.06–0.22 | 0.02–0.20 | 0.16 | 0.18 | 0.8785 |
| | | | –(0.99) | (–0.98) | | | |
| Hip AP moment (Nm/kg) | –0.86 | –0.83 | – | – | 0.28 | 0.21 | 0.8785 |
| | | | –(0.71) | (–0.76) | | | |

Group 1, on the box (n=11); Group 2, not on the box (n=15). * p < 0.0083

peak BF *relevé* ($Med_{Group1}$: 90°, IQR: 80°–90°; $Med_{Group2}$: 70°, IQR: 70°-80°, p < 0.0001) resulted in the rejection of the null hypothesis (Fig. 3); however, ankle PF ROM was not significantly different (p=0.0098) based on the Bonferroni corrected p-value for multiple comparisons (p=0.0083), failing to reject the null hypothesis. We found no significant difference between conditions for C7 displacement (p=0.5055), ankle PF moment (p=0.1484), and hip ML and AP moments (p=0.8785 and p=0.8785, respectively) at peak *relevé* in first position and failed to reject the null hypothesis for Aim 2.

***Post Hoc Power Analysis:*** We computed *post hoc* power analysis using observed sample means, sample variation, and sample sizes from Aim 1. Considering the adjusted alpha level of 0.0083, observed effect sizes were powered at 75.3% with the available sample size (n total=26).

## DISCUSSION

Results from this study indicate that novice dancers who get onto the box of the pointe shoe (Group 1) have significantly greater first MTP extension ROM during barefoot *relevé* than dancers who cannot get onto the box of the pointe shoe (Group 2). Ankle PF ROM did not meet the significance level given the adjusted p-value for multiple comparisons; however, it would have met the significance level were it not for the Bonferroni correction. We did not acquire evidence of other studies that examined WB first MTP-ROM among novice ballet dancers or compared dancers' first MTP-ROM with whole-body posture BF or shod. Studies examining first MTP-ROM among ballet dancers[23,38,39] report varying degrees of movement conceivably because of differences in study design, including weight bearing status (i.e., WB, NWB), method of measurement (i.e., goniometry, 3D motion capture), the position of the dancer's LE's (i.e., turned out in first or second position or parallel in sixth position), and use or not of external support (e.g., ballet *barré*). Regardless, common conclusions derived from these and the current study depict how ballet dancers require a considerable amount of first MTP and ankle ROM to balance with postural stability in demi-pointe[23,38,39] and *en pointe relevé*.[28,32,35]

Group 1 dancers with a median of 90° (IQR: 80° to 90°) WB extension ROM of the first MTP joint stood on the box of the pointe shoe, whereas Group 2 dancers with a median of 70° (IQR: 70° to 80°) did not stand the box of the pointe shoe. Dancers on the box had 13° more ankle PF ($Med_{Group1}$: 168°, $Med_{Group2}$: 155°) during demi-pointe *relevé* than dancers not on the box. Since ankle PF neared the significance level (p=0.0098), we believe these findings are clinically relevant. Dancers on the box had both greater ankle PF and first MTP extension than dancers not on the box. These results are consistent with findings from Wiesler et al.[39] and indicate that weight bearing ankle PF and first MTP extension ROM could be valuable tools in predicting pointe readiness of the novice ballet dancer. Future studies should be dedicated to determining minimal detectable differences (MDD) of weight bearing MTP extension ROM necessary to predict if a dancer will be able to stand on the box of the pointe shoe before commencing pointe work.

Results indicate that dancers in both groups tend to engage the same dominant muscle groups when assuming shod *relevé* in first position at the ballet *barré*, including the trunk extensors, ankle dorsiflexors, hip flexors, and hip abductors. Yet, the possibility of idiosyncrasies in muscle stabilization, strength, and motor control of the foot and LE's between dancers who get onto the box of the pointe shoe and those who do not should be tested using EMG during dance-specific movement. The flexor hallucis longus (FHL) and peroneus longus (PL) muscles are the primary stabilizers responsible for creating rigidity of the longitudinal arch from the subtalar joint into the arch of the foot during axial loading.[49] Dancers roll through demi-pointe or spring from a foot-flat position to assume *en pointe*. Either way, they must press through the stiff pointe shoe to get onto the box, increasing the demand on the foot and ankle plantarflexors. We contend that FHL muscle strength and length likely contribute to the between-group differences in first MTP extension ROM. Future studies should compare dancers who get on the box of the pointe shoe with those that do not for differences between muscle strength of the ankle and foot plantarflexors, such as the FHL,[38] while the dancer is assuming *en pointe* and test for correlation between first MTP and ankle PF ROM and plantarflexor muscle function.

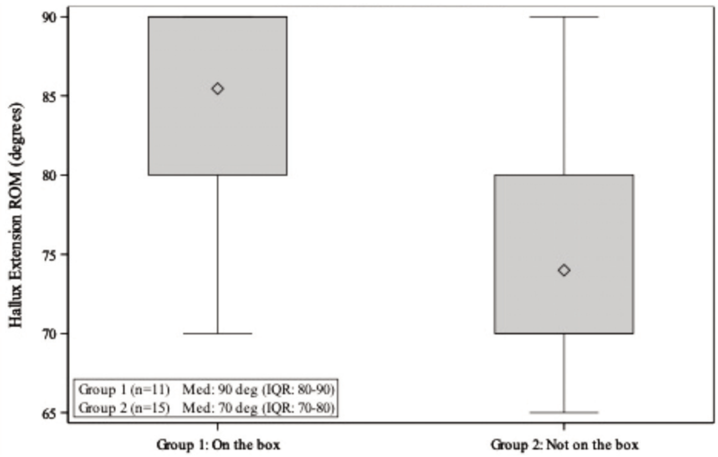


**FIGURE 3.** Aim 1 variable: First MTP extension ROM during *elevé* BF in plumb line parallel position by group (median [IQR=Q1–Q3]). The horizontal line in the middle of each box indicates the median, while the top and bottom borders of the box mark the 75th and 25th percentiles, respectively. The whiskers above and below the box mark the 90th and 10th percentiles, respectively. Hallux angle: PF (+) / DF (–). [a] $p < 0.01$.

There are several limitations and possible confounding factors to consider related to this study. Dancers wore their own pointe shoes for data collection as there are individual differences among dancers' foot and ankle structure and personal shoe preferences (e.g., vamp and/or shank length, shoe width, shoe brand).[25,28] Non-standardization of the pointe shoe could be considered a potential confounder or effect modifier in future studies when evaluating individual differences among participants *en pointe*. It is common practice for dancers to use a ballet *barré* for support to balance while focusing on body position and ballet technique,[50] especially novice dancers who are learning new skills,[19] such as dancing *en pointe*. To ensure safety for the novice dancers participating in this study, dancers performed all dance-specific movements and self-selected warm-ups facing the ballet *barré*. To prevent dancers from pushing down or pulling up on the *barré* with extraneous forces, standardized instruction included verbal cues to only apply "light touch" with two fingers to the *barré* for balance when transitioning on and off pointe while taking frequent rest breaks between trials. We positioned the *barré* in a standardized manner on either side of the two force plates to allow the dancer to stand with one foot on each force plate and symmetrically place both hands on top of the *barré* for recording unimpeded ground reaction force data. A limitation of the current study is that the weight displaced into the ballet *barré* cannot be measured, given that the legs of the *barré* rested on either side of the force plates, not on the force plates. Previous studies reported that the ballet *barré* serves as a contributor to force and torque generation when the dancer applies pressure to it[19] and that muscle activation patterns are highly variable between different levels of dancers (e.g., novice and elite) when using a *barré*.[50] For these reasons, the external support offered by the *barré* should be tested as a potential confounder or effect modifier in future studies considering safety precautions for novice dancers to reduce injury risk. There was a significant difference between groups for time *en pointe* ($Med_{Group1}$: 4 yr, $Med_{Group2}$: 2 yr, $p=0.0202$), possibly related to the 1-year age difference between groups but could be considered a confounding factor and should be explored further with a larger cohort of dancers.

In conclusion, novice dancers who commence pointe work before their bodies are physiologically able to handle the stress and strain may be at a greater risk for injury. The results from this study are meant to shed light on potentially important factors related to pointe readiness, help fill in knowledge gaps related to essential tests and measures specific to adolescent dancers, and directly translate into clinical practice. We recommend incorporating WB first MTP extension and ankle PF ROM and examining postural stability using a dance-specific plumb line when screening dancers, testing for pointe readiness screens, and future studies related to the kinematic assessment of the adolescent dancer.

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## REFERENCES

1. Bowerman EA, Whatman C, Harris N, Bradshaw E. A review of the risk factors for lower extremity overuse injuries in young elite female ballet dancers. *J Dance Med Sci.* 2015;19(2):51-56.

https://doi.org/10.12678/1089-313X.19.2.51
2. Russell JA. Preventing dance injuries: current perspectives. *Open Access J Sports Med.* 2013;4:199-210. https://doi.org/10.2147/OAJSM.S36529
3. Lai JC, Kruse DW. Assessing readiness for en pointe in young ballet dancers. *Pediatr Ann.* 2016;45(1):e21-25. https://doi.org/10.3928/00904481-20151215-01
4. Steinberg N, Siev-Ner I, Peleg S, et al. Extrinsic and intrinsic risk factors associated with injuries in young dancers aged 8-16 years. *J Sports Sci.* 2012;30(5):485-495. https://doi.org/10.1080/02640414.2011.647705
5. Kadel N. Foot and ankle problems in dancers. *Phys Med Rehabil Clin N Am.* 2014;25(4):829-844. https://doi.org/10.1016/j.pmr.2014.06.003
6. Luke AC, Kinney SA, D Hemecourt PA, et al. Determinants of injuries in young dancers. *Med Probl Perform Art.* 2002;17(3):105-112. https://doi.org/10.21091/mppa.2002.3016
7. Russell JA. Preventing dance injuries: current perspectives. *Open Access J Sports Med.* 2013;4:199-210. 10.2147/OAJSM.S36529
8. Richardson M, Liederbach M, Sandow E. Functional criteria for assessing pointe-readiness. *J Dance Med Sci.* 2010;14(3):82-88. https://www.ncbi.nlm.nih.gov/pubmed/21067685.
9. Shah S. Determining a young dancer's readiness for dancing en pointe. *Curr Sports Med Rep.* 2009;8(6):295-299. https://doi.org/10.1249/JSR.0b013e3181c1ddf1
10. Gamboa JM, Roberts LA, Maring J, Fergus A. Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to identify risk characteristics. *J Orthop Sports Phys Ther.* 2008;38(3):126-136. 10.2519/jospt.2008.2390
11. Altmann C, Roberts J, Scharfbillig R, Jones S. Readiness for en pointe work in young ballet dancers are there proven screening tools and training protocols for a population at increased risk of injury? *J Dance Med Sci.* 2019;23(1):40-45. https://doi.org/10.12678/1089-313X.23.1.40
12. DeWolf A, McPherson A, Besong K, et al. Quantitative measures utilized in determining pointe readiness in young ballet dancers. *J Dance Med Sci.* 2018;22(4):209-217. https://doi.org/10.12678/1089-313X.22.4.209
13. Dozzi P, Winter D. Biomechanical analysis of the foot during rises to full pointe: implications for injuries to the metatarsal-phalangeal joints and shoe redesign. *Kinesiol Med Dance.* 1993;94(16):1.
14. Albers D, Hu R, McPoil T, Cornwall M. Comparison of foot plantar pressures during walking and en pointe. *Kines Med Dance.* 1993;15(1):25-32.
15. Weiss DS, Rist RA, Grossman G. When can I start pointe work? guidelines for initiating pointe training. *J Dance Med Sci.* 2009;13(3):90-92.
16. Liederbach M, Hagins M, Gamboa JM, Welsh TM. Assessing and reporting dancer capacities, risk factors, and injuries: recommendations from the IADMS Standard Measures Consensus Initiative. *J Dance Med Sci.* 2012;16(4):139-153. https://www.ncbi.nlm.nih.gov/pubmed/26731091.
17. Russell JA, Yoshioka H. Assessment of female ballet dancers' ankles in the en pointe position using high field strength magnetic resonance imaging. *Acta Radiol.* 2016;57(8):978-984. https://doi.org/10.1177/0284185115616295
18. Russell JA, Shave RM, Kruse DW, et al. Ankle and foot contributions to extreme plantar- and dorsiflexion in female ballet dancers. *Foot Ankle Int.* 2011;32(2):183-188. https://doi.org/10.3113/FAI.2011.0183
19. Laws K. The biomechanics of barre use. *Kines Dance.* 1985;7(4):6-7.
20. Lin CF, Lee IJ, Liao JH, et al. Comparison of postural stability between injured and uninjured ballet dancers. *Am J Sports Med.* 2011;39(6):1324-1331. https://doi.org/10.1177/0363546510393943
21. Fong Yan A, Hiller C, Smith R, Vanwanseele B. Effect of footwear on dancers: a systematic review. *J Dance Med Sci.* 2011;15(2):86-92. https://www.ncbi.nlm.nih.gov/pubmed/21703097.
22. Pearson SJ, Whitaker AF. Footwear in classical ballet: a study of pressure distribution and related foot injury in the adolescent dancer. *J Dance Med Sci.* 2012;16(2):51-56. https://www.ncbi.nlm.nih.gov/pubmed/22687718.
23. Jarvis DN, Kulig K. Kinematic and kinetic analyses of the toes in dance movements. *J Sports Sci.* 2016;34(17):1612-1618. https://doi.org/10.1080/02640414.2015.1126672
24. Dozzi P, Winter D. Biomechanical analysis of the foot during rises to full pointe: implications for injuries to the metatarsal-phalangeal joints and shoe redesign. *Kines Med Dance.* 1993;94(16):1.
25. Cunningham BW, DiStefano AF, Kirjanov NA, et al. A comparative mechanical analysis of the pointe shoe toe box. An in vitro study. *Am J Sports Med.* 1998;26(4):555-561. https://doi.org/10.1177/03635465980260041501
26. Bickle C, Deighan M, Theis N. The effect of pointe shoe deterioration on foot and ankle kinematics and kinetics in professional ballet dancers. *Hum Mov.* 2018;60:72-77. https://doi.org/10.1016/j.humov.2018.05.011
27. Carter SL, Sato N, Hopper LS. Kinematic repeatability of a multi-segment foot model for dance. *Sports Biomech.* 2018;17(1):48-66. https://doi.org/10.1080/14763141.2017.1343864
28. Lin CF, Su FC, Wu HW. Ankle biomechanics of ballet dancers in releve en pointe dance. *Res Sports Med.* 2005;13(1):23-35. https://doi.org/10.1080/15438620590922068
29. Lin C-F, Lee W-C, Chen Y-A, Hsue B-J. Fatigue-induced changes in movement pattern and muscle activity during ballet releve on demi-pointe. *J Appl Bio.* 2016;32(4):350-358. https://doi.org/10.1123/jab.2014-0263
30. Aquino J, Amasay T, Shapiro S, et al. Lower extremity biomechanics and muscle activity differ between 'new' and 'dead' pointe shoes in professional ballet dancers. *Sports Biomech.* 2021;20(4):469-480. https://doi.org/10.1080/14763141.2018.1561931
31. Kizawa M, Yasuda T, Shima H, et al. Effect of toe type on static balance in ballet dancers. *Med Probl Perform Art.* 2020;35(1):35-41. https://doi.org/10.21091/mppa.2020.1005
32. Paderi F, Emmanouil A, Rousanoglou E. Reliability of assessing ballet dancers' postural stability in the unshod and the en pointe relevé position with a smartphone application. *Hum Mov.* 2022;23(2):84-96. https://doi.org/10.5114/hm.2022.109069
33. Penitente G, Hull M, Sands W. Temporal, force and postural analysis of relevé en pointe in novice and intermediate dancers. Presented at: 32nd International Conference of Bio-mechanics in Sports, 2014; Johnson City, TN, USA.
34. Russell JA, Kruse DW, Nevill AM, et al. Measurement of the extreme ankle range of motion required by female ballet dancers. *Foot Ankle Spec.* 2010;3(6):324-330. https://doi.org/10.1177/1938640010374981
35. Veirs KP, Baldwin JD, Rippetoe J, et al. Multi-Segment assessment of ankle and foot kinematics during relevé barefoot and en pointe. *Orthoped Phys Ther Prac.* 2020;32(3):167-175.
36. Lobo da Costa PH, Azevedo Nora FG, Vieira MF, et al. Single leg balancing in ballet: effects of shoe conditions and poses. *Gait Posture.* 2013;37(3):419-423. https://doi.org/10.1016/j.gaitpost.2012.08.015
37. Davenport KL, Simmel L, Kadel N. Hallux valgus in dancers: a closer look at dance technique and its impact on dancers' feet. *J Dance Med Sci.* 2014;18(2):86-92. https://doi.org/10.12678/1089-313X.18.2.86
38. Rowley KM, Jarvis DN, Kurihara T, et al. Toe flexor strength, flexibility and function and flexor hallucis longus tendon morphology in dancers and non-dancers. *Med Probl Perform Art.* 2015;30(3):152-156. https://doi.org/10.21091/mppa.2015.3029
39. Wiesler ER, Hunter DM, Martin DF, et al. Ankle flexibility and injury patterns in dancers. *Am J Sports Med.* 1996;24(6):754-757. https://doi.org/10.1177/036354659602400609
40. Jarvis DN, Kulig K. Lower extremity biomechanical demands

during saut de chat leaps. *Med Probl Perform Art.* 2016;31(4):211-217. 10.21091/mppa.2016.4039
41. Wong-Baker Faces Foundation. Wong-Baker FACES® Pain Rating Scale. http://www.WongBakerFACES.org. 1995. Accessed Nov 2016.
42. Veirs K, Rippetoe J, Baldwin J, et al. Evaluation of the effects of first metatarsophalangeal joint mobility on the young ballet dancer's ability to assume the en pointe using a multi-segment foot model [dissertation]. Oklahoma Univ Health Sciences, 2019. https://www.proquest.com/scholarly-journals/multi-segment-assessment-ankle-foot-kinematics/docview/2636862266/se-2?accountid=201395.
43. Bruening DA, Cooney KM, Buczek FL. Analysis of a kinetic multi-segment foot model. Part I: Model repeatability and kinematic validity. *Gait Posture.* 2012;35(4):529-534. https://doi.org/10.1016/j.gaitpost.2011.10.363
44. Chen MJ, Fan X, Moe ST. Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: a meta-analysis. *J Sports Sci.* 2002;20(11):873-899. https://doi.org/10.1080/026404102320761787
45. Abraham A, Dunsky A, Hackney ME, Dickstein R. Kinematic and kinetic analysis of repeated and static eleve in adolescent female dance students. *J Dance Med Sci.* 2018;22(1):33-43. https://doi.org/10.12678/1089-313X.22.1.33
46. Robertson G, Caldwell G, Hamill J, et al. *Research Methods in Biomechanics,* 2nd ed. Champaign, IL: Human Kinetics; 2013.
47. Sugrue PA, McClendon J Jr, Smith TR, et al. Redefining global spinal balance: normative values of cranial center of mass from a prospective cohort of asymptomatic individuals. *Spine (Phila Pa 1976).* 2013;38(6):484-489. https://doi.org/10.1097/BRS.0b013e318273a1c0
48. Kwon YH, Wilson M, Ryu JH. Analysis of the hip joint moments in grand rond de jambe en l'air. *J Dance Med Sci.* 2007;11(3):93-99.
49. Femino J, Trepman E, Chisholm K, Razzano L. The role of the flexor hallucis longus and peroneus longus in the stabilization of the ballet foot. *J Dance Med Sci.* 2000;4(3):86-89.
50. Krasnow D, Ambegaonkar J, Wilmerding M, et al. Electromyographic comparison of grand battement devant at the barre, in the center, and traveling. *Med Probl Perform Art.* 2012;27(3):143-155. https://doi.org/10.21091/mppa.2012.3026

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