# Measurement of the Extreme Ankle Range of Motion Required by Female Ballet Dancers

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*Foot Ankle Spec* 2010 3: 324 originally published online 25 June 2010
DOI: 10.1177/1938640010374981

〈 Clinical Research 〉

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Abstract: *Female ballet dancers require extreme ankle motion, especially plantar flexion, but research about measuring such motion is lacking. The purposes of this study were to determine in a sample of ballet dancers whether non–weight-bearing ankle range of motion is significantly different from the weight-bearing equivalent and whether inclinometric plantar flexion measurement is a suitable substitute for standard plantar flexion goniometry. Fifteen female ballet dancers (5 university, 5 vocational, and 5 professional dancers; age 21 ± 3.0 years) volunteered. Subjects received 5 assessments on 1 ankle: non–weight-bearing goniometry dorsiflexion (NDF) and plantar flexion (NPF), weight-bearing goniometry in the ballet positions demi-plié (WDF) and en pointe (WPF), and non–weight-bearing plantar flexion inclinometry (IPF). Mean NDF was significantly lower than WDF (17° ± 1.3° vs 30° ± 1.8°, P < .001). NPF (77° ± 2.5°) was significantly lower than both WPF (83° ± 2.2°, P = .01) and IPF (89° ± 1.6°, P < .001), and WPF was significantly lower than IPF (P = .013). Dorsiflexion tended to decrease and plantar flexion tended to increase with increasing ballet proficiency. The authors conclude that assessment of extreme ankle motion in female ballet dancers is challenging, and goniometry and inclinometry appear to measure plantar flexion differently.*

**Levels of Evidence: Diagnostic, Level II**

Keywords: ankle; goniometry; inclinometry; dance; ballet

Female ballet dancers require large ranges of motion in dorsiflexion and plantar flexion.[1-3] This is particularly exemplified by the plantar flexion needed to rise *en pointe* (Figure 1).[3-6] Such extremes challenge ankle range-of-motion assessment in ballet dancers because the motion is greater than normative data reported for the ankle using goniometry.[7,8] In light of this, the standardization of methods to measure ankle range of motion in female ballet dancers is important for improved understanding of the demands of ballet on this joint and surrounding structures and for measurement of ballet dancers' ankle range of motion during rehabilitation from ankle injury or surgery.

**Figure 1.**

A ballet dancer standing *en pointe*.

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While various studies have measured ankle range of motion in ballet dancers,[3,5,9-16] none could be found comparing different measurement techniques nor evaluating motion in the weight-bearing positions of *demi-plié* (maximum dorsiflexion) and *en pointe* (maximum plantar flexion). Therefore, the primary aims of this project were to determine whether non–weight-bearing ankle range of motion is significantly different from weight-bearing ankle range of motion in *demi-plié* and *en pointe* and whether inclinometric plantar flexion measurement as proposed by Novella[5,6] is a suitable substitute for standard plantar flexion goniometry.

**Table 1.**

Age and Dance Participation (Mean ± SD) of the Subjects According to Ballet Proficiency Level

| Parameter | University (n = 5) | Vocational (n = 5) | Professional (n = 5) | All Subjects (N = 15) |
|---|---|---|---|---|
| Age[a,y] | 20 ± 0.9 | 23 ± 3.3 | 22 ± 3.6 | 21 ± 3.0 |
| Years dancing[a] | 15 ± 3.0 | 18 ± 4.5 | 17 ± 2.5 | 17 ± 3.5 |
| Years dancing *en pointe*[b] | 3 ± 1.3 | 10 ± 4.4 | 11 ± 4.0 | 8 ± 4.8 |

[a]No significant differences among levels of proficiency.
[b]Significant differences between university and other levels: vocational ($P = .03$), professional ($P = .01$).

## Materials and Methods

### Subjects

Power calculations were performed to estimate sample sizes required for this study. A desired power value of 0.90 was used. For comparing non–weight-bearing and weight-bearing dorsiflexion, 6 subjects were required. For comparing non–weight-bearing and weight-bearing plantar flexion, the required sample size was 9. For a comparison of non–weight-bearing goniometry plantar flexion to non–weight-bearing inclinometry plantar flexion, a minimum of 11 subjects was needed.

> "... the standardization of methods to measure ankle range of motion in female ballet dancers is important for improved understanding of the demands of ballet on this joint and surrounding structures ...."

Fifteen female ballet dancers (mean age, 21 ± 3.0 years) volunteered. Of these, 5 were university dancers, 5 were vocational (ie, preprofessional training) dancers, and 5 were professional ballet dancers. All subjects completed a demographic questionnaire that included information about their years of dance participation and their years of experience dancing *en pointe*. Mean age and ballet participation data for the subjects at each level of ballet are given in Table 1.

The right ankle was studied unless a subject reported a substantial previous injury or any current injury to that ankle. In such a case, the left ankle was studied. Three of the 15 ballet dancers reported a prior ankle sprain; although they indicated that their symptoms had resolved, the uninjured left ankles of these 3 subjects were used to ensure that previous injury did not affect the data. The appropriate research ethics committee approved the study protocol, and all subjects gave their informed consent.

### Non–weight-bearing Goniometry

After completing the demographic questionnaire, subjects warmed up their ankles and feet in their customary way until they felt comfortable standing *en pointe*. Following this warm up, each subject was seated on an examination table with her feet bare and her knees flexed between approximately 45° and 60°[17] to prevent the gastrocnemius muscle from limiting dorsiflexion.[18]

All goniometric measurements were made by a single examiner using a standard 30-cm goniometer to measure non–weight-bearing active dorsiflexion (NDF) and plantar flexion (NPF). The proximal arm of the goniometer was aligned with the fibula, the distal arm was aligned parallel to the fifth metatarsal, and the rotational axis was slightly below the distal tip of the lateral malleolus.[8] The convention was followed of neutral position being 0°[7,8] and ankle motion being the number of degrees of angular movement from that position in either a dorsal or plantar direction.

### Non–weight-bearing Inclinometry

Maximum plantar flexion was then assessed with a bubble inclinometer (Fabrication Enterprises, White Plains, New York). The device incorporates a gravity-mediated spirit level containing a bubble that aligns with a dial gradated in degrees. The inclinometer plantar flexion (IPF) technique was adapted from the method of Novella.[5,6] Novella used the *tendu* ballet position (ie, his subjects stood holding their lower extremity with slight hip flexion, knee extension, and plantar flexion). However, for this research, the identical seated position was selected as that used for the plantar flexion goniometry.

The subject was barefoot and asked to maximally plantar flex the ankle and hold it still until tibial and dorsal foot inclinometry measurements were completed (less than 30 seconds). The first placement of the inclinometer was along the anterior border of the distal tibia, where the inclinometer dial's zero mark was aligned to the bubble. Then the

inclinometer was repositioned on the dorsal foot across the distal talus and navicular. The procedure is shown in Figure 2.

Then, the reading of the inclinometer in degrees was recorded. The difference between the inclinometry value of the dorsal foot and that of the distal tibia indicated the subject's plantar flexion. A difference of 0° indicated that the ballet dancer's tibia and dorsal foot described a 180° angle (corresponding to plantar flexion of 90°). A positive difference indicated that the angle between the tibia and foot was greater than 180° (plantar flexion greater than 90°). A negative difference indicated this angle to be less than 180° (plantar flexion less than 90°).

### Weight-bearing Goniometry

Following the non–weight-bearing range-of-motion assessments, subjects put on their *pointe* shoes in their usual way. No attempt was made to standardize the shoes by either brand or relative newness; this allowed each ballet dancer to use the shoes most comfortable and suitable for her. Subjects were instructed to stand on a platform to allow the goniometer to be placed appropriately alongside her foot and ankle in the positions of *demi-plié* and *en pointe* (Figure 3).

First, weight-bearing dorsiflexion (WDF) was measured in *demi-plié*. Subjects were instructed to lower into as deep a *demi-plié* as possible. Parallel position of the feet was used because the limited support surface area available on the apparatus did not allow externally rotated lower extremity positions; the parallel position coincides with other authors' protocols.[9,19-22] Using the same anatomical landmarks and measuring conventions as in the non–weight-bearing goniometry, the angle of dorsiflexion was recorded. Then, the subject stood *en pointe*, and weight-bearing plantar flexion (WPF) was similarly recorded.

### Total Range-of-Motion Calculation

Finally, to obtain total ankle range of motion (TAROM), a ballet dancer's dorsiflexion measurement was added to her plantar flexion measurement. Scores for both non–weight-bearing goniometry and weight-bearing goniometry in the ballet positions were accomplished this way. That is,

$$\text{TAROM}_{NWB} = \text{NDF} + \text{NPF}$$

and

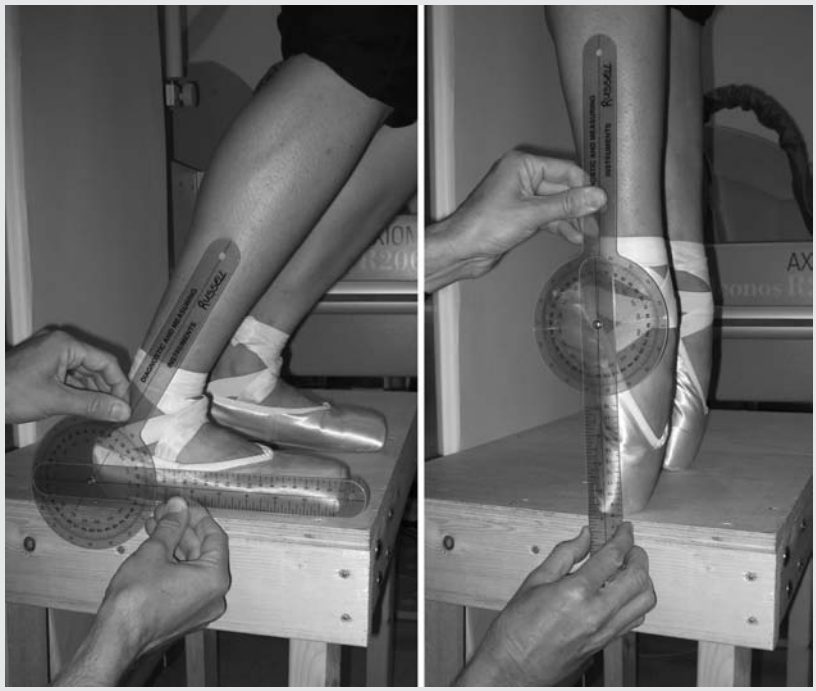
$$\text{TAROM}_{WB} = \text{WDF} + \text{WPF}.$$

**Figure 2.**

Inclinometric measurement of ankle plantar flexion. (Left) Tibial position where the dial is set to 0°. (Right) Position of the inclinometer where the dorsal foot reading is taken.

**Figure 3.**

Goniometric measurement of ankle range of motion in weight bearing. (Left) *Demi-plié* dorsiflexion. (Right) *En pointe* plantar flexion.



### Reliability of the Goniometric and Inclinometric Measurement Techniques

To establish the intratester reliability of the clinician in the present study, a separate group of 6 uninjured ankles were measured for clinical non–weight-bearing dorsiflexion and plantar flexion according to the same standard method used throughout the present study.[8] Three trials were accomplished on each ankle. Three observations of the same 6 ankles also were obtained with the inclinometry technique.[6]

To assess the reliability of the examiner's technique, these data were analyzed with 1-way analysis of variance with repeated measures. Intraclass correlation coefficients (ICCs) were calculated from the mean square values in the analysis of variance (ANOVA) summary table.[23] ICCs for the reliability data were 0.99 for both goniometry and inclinometry, showing that the examiner was reliable in executing the required measurements. Coefficients of variation (CVs) for these data also show good agreement among the examiner's trials: dorsiflexion CV = 10%, plantar flexion CV = 7%, inclinometry CV = 1%.

### Data Analyses

Repeated-measures ANOVA, with 1 factor between (proficiency level of ballet dancer) and 1 factor within (measurement method) subjects was used to determine if differences existed between methods of measuring dorsiflexion, among methods of measuring plantar flexion, and among levels of dance proficiency for dorsiflexion and plantar flexion. A Student *t* test for dependent pairs was used to analyze TAROM data for differences between the non–weight-bearing and weight-bearing ballet position range of motion. One-way ANOVA assessed each type of TAROM among the different dancer proficiency levels. Following the ANOVAs, Tukey's post hoc test was employed to assess pairwise differences. In addition, CVs were determined for dorsiflexion and total range of motion (2 measurement conditions each) and plantar flexion (3 measurement conditions). An alpha value of .05 was used for all analyses.

**Table 2.**

Range-of-Motion Values in Female Ballet Dancers' Ankles

| Measurement Method | Mean ± SD Dorsiflexion | Mean ± SD Plantar Flexion |
|---|---|---|
| Active non–weight-bearing goniometry | NDF = 17° ± 1.3° | NPF = 77° ± 2.5° |
| Differences | vs WDF: $P < .001$ | vs WPF: $P = .01$<br>vs IPF: $P < .001$ |
| Active non–weight-bearing inclinometry | NA | IPF = 89° ± 1.6° |
| Differences | | vs NPF: $P < .001$<br>vs WPF: $P = .013$ |
| Weight-bearing goniometry | WDF = 30° ± 1.8° | WPF = 83° ± 2.2° |
| Differences | vs NDF: $P < .001$ | vs NPF: $P = .01$<br>vs IPF: $P = .013$ |

Abbreviations: IPF, non–weight-bearing inclinometry plantar flexion; NDF, non–weight-bearing goniometry dorsiflexion; NPF, non–weight-bearing plantar flexion; WDF, weight-bearing dorsiflexion in *demi-plié*; WPF, weight-bearing plantar flexion *en pointe*.

## Results

Overall, mean NDF was significantly different from WDF ($P < .001$), with values of 17° ± 1.3° and 30° ± 1.8°, respectively. The 3 plantar flexion methods were significantly different from one another, and post hoc analysis indicated that mean NPF of 77° ± 2.5° was significantly less than both mean WPF of 83° ± 2.2° ($P = .01$) and mean IPF of 89° ± 1.6° ($P < .001$). In addition, mean WPF was significantly less than IPF ($P = .013$). Range-of-motion data for all subjects appear in Table 2.

The range-of-motion data are broken down by ballet proficiency level in Table 3. Interestingly, dorsiflexion ability decreased with increasing ballet proficiency; the university ballet dancers' mean dorsiflexion was significantly greater than that of the professional ballet dancers ($P = .01$ for both non–weight-bearing and *demi-plié* values). Plantar flexion showed the tendency to increase with increasing ballet proficiency level, although there were no significant differences among NWB goniometric plantar flexion values. Plantar flexion in the university dancers was significantly different from the professional dancers for both *en pointe* and inclinometric plantar flexion ($P = .03$).

Table 3 also contains the TAROM data. There was a significant difference between $TAROM_{NWB}$ and $TAROM_{WB}$ ($P < .001$). Not surprisingly, the latter was always the greater of the two. However, no significant differences were found among the dance proficiency levels for either method of TAROM measurement. The professional ballet dancers had the smallest TAROM of the 3 groups, with clinical measurement and the largest TAROM of the 3 groups when measured in the ballet positions.

The coefficients of variation revealed that dorsiflexion was the most variable of the measurements undertaken (CV = 24%). CV was 9% for both plantar flexion and total range of motion.

## Discussion

The primary aims of this research were to determine in female ballet dancers whether non–weight-bearing ankle range

**Table 3.**

Range-of-Motion Data by Ballet Level (Mean ± SD)

| Measurement | University (n = 5) | Vocational (n = 5) | Professional (n = 5) |
|---|---|---|---|
| NDF[a] | 22° ± 5.3° | 18° ± 3.6° | 10° ± 6.1° |
| WDF[b] | 35° ± 7.9° | 27° ± 7.3° | 26° ± 5.1° |
| NPF[c] | 70° ± 12.0° | 81° ± 11.7° | 80° ± 3.1° |
| WPF[d] | 74° ± 6.1° | 86° ± 7.2° | 90° ± 11.7° |
| IPF[e] | 83° ± 7.1° | 88° ± 8.3° | 95° ± 1.9° |
| Total NWB ankle motion[f] | 92° ± 15.0° | 98° ± 8.2° | 90° ± 5.7° |
| Total WB ankle motion[f] | 109° ± 13.7° | 113° ± 8.7° | 116° ± 10.4° |

Abbreviations: IPF, non–weight-bearing inclinometry plantar flexion; NDF, non–weight-bearing goniometry dorsiflexion; NPF, non–weight-bearing plantar flexion; NWB, non–weight bearing; WB, weight bearing; WDF, weight-bearing dorsiflexion in *demi-plié*; WPF, weight-bearing plantar flexion *en pointe*.

[a]University and professional significantly different, $P = .01$.

[b]University and professional significantly different, $P = .01$.

[c]No significant differences among proficiency levels.

[d]University and professional significantly different, $P = .03$.

[e]University and professional significantly different, $P = .03$.

[f]Total NWB versus total WB significantly different for all proficiency levels, $P < .001$.

of motion is different from weight-bearing ankle range of motion in *demi-plié* and *en pointe* and whether inclinometric plantar flexion measurement is an accurate substitute for standard plantar flexion goniometry. We found that weight-bearing range of motion was greater than non–weight-bearing range of motion; this was true for dorsiflexion, plantar flexion, and total range of ankle motion. This comparison between weight bearing and non–weight bearing has been reported previously for dorsiflexion.[24] Intuitively it is expected because of the ability of a ballet dancer to apply her body weight to the lever system of the lower extremity, thereby incorporating increased mechanical advantage in *demi-plié* and *en pointe*. In *demi-plié*, the ballet dancer applies her body weight to press the leg-foot linkage into greater dorsiflexion. During the rise *en pointe*, the forces around the ankle and foot[25,26] may accentuate the loading of the foot's longitudinal arches in the dorsal direction with a resultant forcing of the ankle and foot into plantar flexion. Consequently, both of these conditions would allow the ballet dancer to attain a greater angle of ankle movement in weight bearing.

We further found that dorsiflexion decreased with increasing dance proficiency level while plantar flexion tended to increase with increasing dance proficiency. These results may stem from the extra years that professional ballet dancers have spent trying to improve plantar flexion flexibility.[3] It is also presumed that higher level ballet dancers typically spend more rehearsal and performance time plantar flexed on *demi-pointe* and *en pointe* than they do dorsiflexed in *demi-plié* while fulfilling the requirements of their ballet employment.

Another reason some higher level ballet dancers exhibit decreased dorsiflexion may relate to the presence of anterior impingement exostoses on the anterior edge of the tibial plafond and the dorsal sulcus of the talar neck. These are propagated by the repeated forced dorsiflexion ballet dancers undergo in *demi-plié* and can limit dorsiflexion range of motion.[27-31] Although it is a weakness of the available medical literature that studies report an empirical reduction in dorsiflexion accompanying anterior exostosis impingement without supplying actual range-of-motion data, it has been reported that anterior exostoses were present in 59.3% of ballet dancers and only 4% of nondancers.[30]

Our data for dorsiflexion and plantar flexion of ballet dancers were greater than data of some researchers who used similar protocols[14] but less than the data reported by others.[3,16] Hamilton et al[3] studied a variety of musculoskeletal characteristics in professional ballet dancers, including ankle range of motion. Their non–weight-bearing dorsiflexion value in females compares favorably with the value for the female professionals in our study (means were virtually equal), but their mean plantar flexion value was substantially greater (113° vs 80°). The mean age of their ballet dancers was 29.3 years, somewhat older than the professional ballet dancers in our research (mean age 22 years). This may translate to additional years of professional experience that could conceivably result in the larger plantar flexion they reported.

Average *en pointe* plantar flexion values of 52.9° for the right ankle and 53.8° for the left have been reported using a motion capture protocol with classical ballet dancers.[12] These values are substantially lower than our data and those of other investigators.[3,14,16] Several methodological issues may provide an explanation for these researchers' low measurements. They attempted to measure plantar flexion from reflective markers placed at various points on the leg, ankle, and foot, but they did not specify what position of the ankle they considered to be the 0° starting position. Furthermore, one of the foot markers was placed, by their description, between the second and third metatarsophalangeal joints. From an anatomical viewpoint, this placement is not precise when a dancer is wearing a *pointe* shoe. Depending on its actual location, it may have contributed to their lower values.

With regard to the inclinometric plantar flexion measurement method of Novella,[5,6] we found this method to be

not comparable to goniometric measurement of plantar flexion. Values obtained by this inclinometry technique require a conversion to compare them to traditional goniometry values, a task accomplished by adding 90 to the inclinometric plantar flexion values. This conversion presumes that 0° of plantar flexion is the position at which the foot and leg are perpendicular to one another, or ankle neutral position.[7,8,32] Novella[5] regarded parallel alignment of the tibia and dorsal talonavicular region as 0°, so his plantar flexion values were negative on the dorsal side of 0° and positive on the plantar side of 0°. His reported values ranged from –12° to +25°, with a mean of +8°.[6] Converting these according to our described calculation yields a range of 78° to 115°, with a mean of 98°.

Novella's mean plantar flexion value was more than 11° greater than our clinical measurement technique and more than 5° greater than our *en pointe* measurement technique. Measuring active range of motion with the limb in an open kinetic chain as he recommended (hip slightly flexed, knee fully extended, and ankle maximally plantar flexed) may introduce error if the subject cannot remain completely still. In our study, we modified the testing position to correspond to the position used for active goniometry[17] (subject seated, knee flexed 45°-60°, ankle maximally plantar flexed) as it has been previously reported that different patient positions during plantar flexion assessment do not decrease measurement reliability.[33] In addition, the relative amount and compressibility of tissue along the anterior border of the tibia may be a source of error in this inclinometry method due to variability in the support surface for the instrument. We noted that even small changes in the position of an inclinometer can create concomitant changes in angular readings.

As far as we can determine, goniometry of weight-bearing ankle motion in ballet dancers *en pointe* has not been reported previously. In establishing this method, it is reasonable to assume that the present study contained underlying limitations. Chief among these were the practical matters of measuring ankle movement in the most extreme positions possible using a goniometric procedure that is standardized to substantially smaller ranges of motion and trying to do so with the foot encased in a *pointe* shoe. Although this was an initial study into the topic and statistical power calculations indicated that we had enough subjects overall, the sample size of 5 dancers in each of the 3 dance proficiency levels limits generalizability within these categories. Also, in inclinometry of ballet dancers' plantar flexion, the potential for variability inherent in the technique may have introduced variability.

In conclusion, goniometric and inclinometric measurement of ankle range of motion in female ballet dancers is challenging, particularly for the extreme amount of plantar flexion required to dance *en pointe*. Most studies of plantar flexion in ballet dancers, including ours, reveal a range much larger than the normative value of 50°. Thus, standard goniometry may not be the best method of assessing this motion in ballet dancers. In addition, goniometry and inclinometry appear to evaluate ankle plantar flexion differently. We recommend adoption of inclinometry for ankle range-of-motion assessment because it incorporates landmarks that are easier to consistently locate than those of goniometry and does not require estimation of a joint axis. However, normative values for inclinometry must be ascertained with future research, as they do not currently exist. FAS

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