A reprint from

Impulse

The International Journal of Dance Science, Medicine, and Education

Human Kinetics Publishers

Impulse, 1993, **1**, 21-38

Physiological Assessment to Determine Readiness for Pointe Work in Ballet Students

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This study explores the physiological determinants for progressing to *pointe* work in ballet. Strength and flexibility were assessed in three groups of prepubescent females. Group I (n=11) were dancers who averaged 1.22 years of pointe work, Group II (n=11) were dancers who had not yet begun pointe training, and Group III (n=10) were gender- and age-matched nondancer controls. Statistically significant differences in range of motion (at the $P<0.05$ level) were found between dancers and controls, with the dancers demonstrating both increased dorsiflexion and plantarflexion. However, relatively few statistically significant differences were found between the dancers and controls with regard to strength at the knee and ankle (utilizing the Cybex II dynamometer protocol). It is hypothesized that attainment of increased range of motion, particularly into plantarflexion, is the primary determinant of the ability of the young dancer to progress to pointe work, with strength probably a secondary concern.

Organized training in dance has become increasingly popular for children and adolescents. There have been recent suggestions that dance training generally, and ballet in particular, is now the most popular exercise activity for children in North America, superseding such well-known organized sports as Little League baseball and Pop Warner football. With this growth of interest have come new challenges to the physician who cares for children and adolescents, as well as for dance teachers.

The dance teacher and the physician must always be cognizant of the interaction between the demands of specific dance training and the growth and development

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of children. Perhaps the most common query from parents of daughters in ballet training is, "When may my child dance *en pointe*?" A review of the current dance and exercise literature gives few guidelines or physiological parameters to help answer this question. As with most other sports and exercise activities for children and adolescents, there are two basic concerns. First, when can the child safely perform the maneuver in question without risking injury to the growing bones and joints, and in particular to the growth tissue? Second, how much training is required to ensure that the child can effectively perform the desired technique? These dual concerns with safety and efficacy are common to most activities for children.

There are few published reports of injuries incurred by children undertaking premature pointe work. We are aware of one case report of physeal injury to the first metatarsal, and have ourselves encountered several cases of apparent tissue injury in association with early pointe training, one of which involved stress fracture of the first metatarsal. A second report was that of a young woman who, in the early stages of pointe work, developed onset of first metatarsal phalangeal joint pain. She ultimately was diagnosed as having osteochondral injury to the articular cartilage of the first metatarsal.

It has been our own clinical practice to recommend to parents that the child should not dance en pointe before age 10, and only after at least 3 years of relatively disciplined and directed ballet training. In order to attempt to define more specific physiological and biomechanical parameters that might help guide the physician, dance teacher, and parent as to the appropriate time for a given child to go en pointe, the second author (L.M.) suggested that analysis of strength, range of motion, and endurance of lower extremity musculature could be studied with a vertically designed comparison of three cohorts: one group of young dance students who had been working en pointe for at least 1 year, a second group who had not yet been determined empirically by their teachers as ready to begin pointe work, and a third control group of athletic females of similar age who were not involved in dance training.

This attempt to define specific physiological parameters for progressive training in young ballet students is, to the best of our knowledge, the first of its kind. The closest parallels to this study deal with speed skaters (Nemoto, Kanehisa, & Miyashita, 1990), soccer players (Öberg, Möller, Gillquist, & Ekstrand, 1986), and elite female track and field athletes (Housh, Thorland, Tharp, Johnson, & Cisar, 1984). One of the most relevant attempts to establish normative values for the muscle groups of the lower extremity has prepubescent and postpubescent athletes as its subject population (Tabin, Gregg, & Bonci, 1985).

Several of the large-scale studies of dancers, such as those of Hamilton, Hamilton, Marshall, and Molnar (1992) and Micheli, Gillespie, and Walaszek (1984), were conducted under the auspices of medical doctors with a specialization in dance medicine, and focus on injury prevention at the level of professional ballet companies. Bejjani (1987) has a similar interest in injuries, which he pursues largely through a comparison of elite dancers and athletes. Of the dance science oriented studies, Chmelar, Shultz, Ruhling, Fitt, and Johnson (1988), Kirkendall and Calabrese (1983), and Mostardi, Porterfield, Greenberg, and Goldberg (1983) are noteworthy for their concern with upper leg strength: Chmelar et al. compare ballet and modern dancers at the university and professional levels; Kirkendall and Calabrese compare ballet dancers and athletes in a variety of sports; and Mostardi et al. view musculoskeletal capabilities as part of a larger profile of ballet dancers. Pekkarinen, Litmanen, and Mahlamäki (1989) looked at 9- to 16-year-old male ballet students, but, unfortunately used a strength test that does not correlate easily with our study; Claessens, Beunen, Nuyts, Lefevre, and Wellens (1987) dealt with a subject base similar to ours and found comparable strength/flexibility correlations, but also used different testing procedures.

Methods

Female volunteers were recruited from dance classes in Boston and from among their nondancing friends. Similarities in age, height, and weight were factors in accepting subjects for this study. As described in Table 1, the 32 subjects were divided into three groups: En Pointe (EP), Group I (n=11); No Pointe (NP), Group II (n=11); and Control (C), or nondancing Group III (n=10). The NP group turned out to be an average of 1.18 years younger than the EP group, and slightly shorter and lighter than the other two groups. Because a close correlation between these variables and strength has been demonstrated in numerous studies (Bäckman & Öberg, 1989; Falkel, 1978; Gilliam, Villanacci, Freedson, & Sady, 1979; Molnar & Alexander, 1974; Nosse, 1982; Sepic, Murray, Mollinger, Spurr, & Gardner, 1986; Weltman et al., 1988), they had to be taken into consideration in analyzing strength test results. The EP and NP groups began ballet training at very similar ages but, because of the difference in chronological age, the EP subjects had danced for more than a year longer at the time of testing (EP = 5.55 yrs, NP = 4.34 yrs on average of dance training). The subjects in the EP group had danced en pointe an average of 1.22 years.

After each subject signed a standard consent form, an injury history was taken and her feet and ankles were examined by the physicians involved in the study. All had normal exam without relevant injury except for two. One EP subject had limited range of motion in dorsiflexion due to a recent ankle sprain.

Table 1 Subject Profiles

Subjects		Age	Height (cm)	Weight (kg)	Yrs ballet
En pointe	Mean	11.01	141.94	37.17	5.55
(n=11)	*SD*	0.71	11.40	7.81	1.36
No pointe	Mean	9.83	133.22	30.25	4.34
(n=11)	*SD*	0.93	7.22	4.01	1.25
Controls	Mean	10.35	141.17	33.04	NA
(n=10)	*SD*	0.70	5.87	2.82	NA

Another subject (an NP) reported a recent ankle sprain but had full range of motion with strength. Two types of testing were then administered by a registered physical therapist: (a) passive range of motion (ROM) at the ankle, using standard goniometer procedures to measure degrees of plantarflexion and dorsiflexion; and (b) Cybex isokinetic testing for peak torque at the ankle and knee, as described in the Cybex test manual (1983). Specifically, the tests were as follows: dorsiflexion and plantarflexion for the ankle with the knee at 0° and at 90°, measured at angular velocities of 30° and 120°/second; flexion and extension for the knee at angular velocities of 60° and 180°/second. In all cases each subject performed five pretest repetitions, followed by five repetitions for the knee at 60°/second and 20 repetitions at 180°/second, and five repetitions for the ankle at 30°/second and 20 repetitions at 120°/second.

Peak torque ratios of ankle plantarflexion to dorsiflexion and knee extension to flexion were also calculated in all cases to describe the extent of muscle imbalance present in the agonist-antagonist muscle group being tested. All of the isokinetic test results, calibrated in Newton meters, were measured directly from the Cybex generated graphs. They were entered, along with the ROM data, into a Microsoft Excel 2.2 spreadsheet. These data were then transferred to, and analyzed statistically with, the JMP, Version 2 program from SAS Institute. The post hoc Tukey-Kramer HSD (honestly significant difference) test was used to determine statistically significant differences between the three groups at the $P<0.05$ level. As an example of JMP output, see Figure 1, which illustrates that

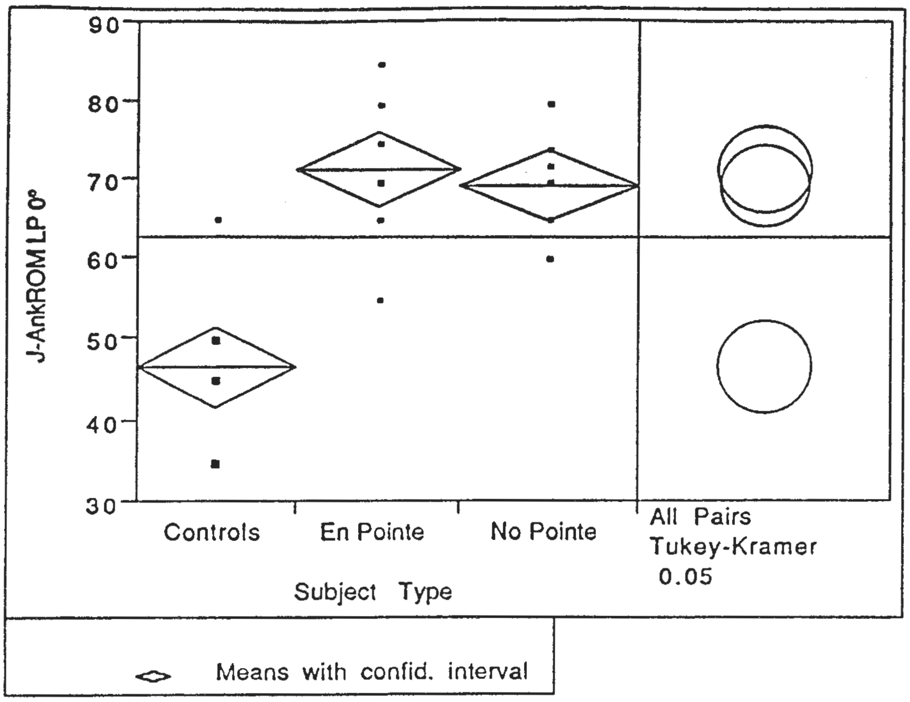

Figure 1. Range of motion. Left plantarflexion, three subject groups, knee at 0°.

the range of motion of the EP and NP groups differs significantly from that of the C group, but not from each other. In addition to peak torque, endurance data were also gathered for all of the Cybex tests, but these are not shown here and are discussed only briefly as their reliability is in question (see Discussion section).

Results

The ROM results are displayed in Figure 2, in terms of degrees of dorsiflexion and plantarflexion at the ankle for each of the three groups, with the knee at 0° and at 90°. The pattern for all eight tests was the same, with the EP group scoring highest (i.e., demonstrating greatest flexibility), the NP group next, and the C group lowest. The difference between EPs and NPs was not statistically significant in any case although, again, the NPs were always lower. The EPs were significantly higher than the Cs on seven of the eight tests, and the NPs were significantly higher on four.

The mean results of the Cybex testing of the ankle, expressed in Newton meters, are shown in Figures 3 and 4. The results for the knee are shown in Figure 5. In these results another, almost totally reversed, pattern emerges: in 11 of the 16 tests at the ankle and all of the 8 tests at the knee, the C group demonstrated the greatest strength. The NP group was generally lowest, scoring higher than the EP group on only 7 of 24 tests overall, and never outscoring the C group. The means of the three groups in each test tended to be similar at both the ankle and knee; out of 48 permutations (3 groups × 16 tests) involving strength at the ankle, only five differences were statistically significant (Figures 3 and 4). All of those were accounted for by the lower NP means. At the knee, the C's means were higher than both of the other groups on all eight tests, but never significantly so (Figure 5). The EPs scored higher than the NPs on four tests, lower on three, and the same on one, always by far less than statistically significant differences (Figure 5).

Where ratios of peak torque generated in plantarflexion over dorsiflexion at the ankle are concerned (Figure 6), the NP group was highest in seven of eight tests (i.e., demonstrated greatest muscle imbalance) and the differences were significant relative to the Cs in two cases and the EPs in one. As Burnie (1987) and Fugl-Meyer, Sjostrom, and Wahlby (1980) point out, there appears to be little consensus in the literature regarding normative value for ratios of opposing muscle groups at the ankle. Further, normative values in our study age group have not yet been published. Age, sex, athletic history, and test protocol are some of the influences on this finding. Nonetheless, the normative data for adults published in Davies' *Compendium* (1984) indicate ratios of 4:1 at 30°/second and 3:1 at 120°/second.

All four of our tests at 30°/second are well below those norms, with marginally different values among the three groups. At 120°/second, however, there is far greater variation, especially regarding the NPs, but also the EPs on the right ankle with the knee at 90°. These variations appear to result in part from extreme plantarflexor/dorsiflexor imbalances in three subjects, rather than from measurement error. At the knee (Figure 7), the three groups traded positions among tests, with no apparent pattern and within a very narrow range of values.

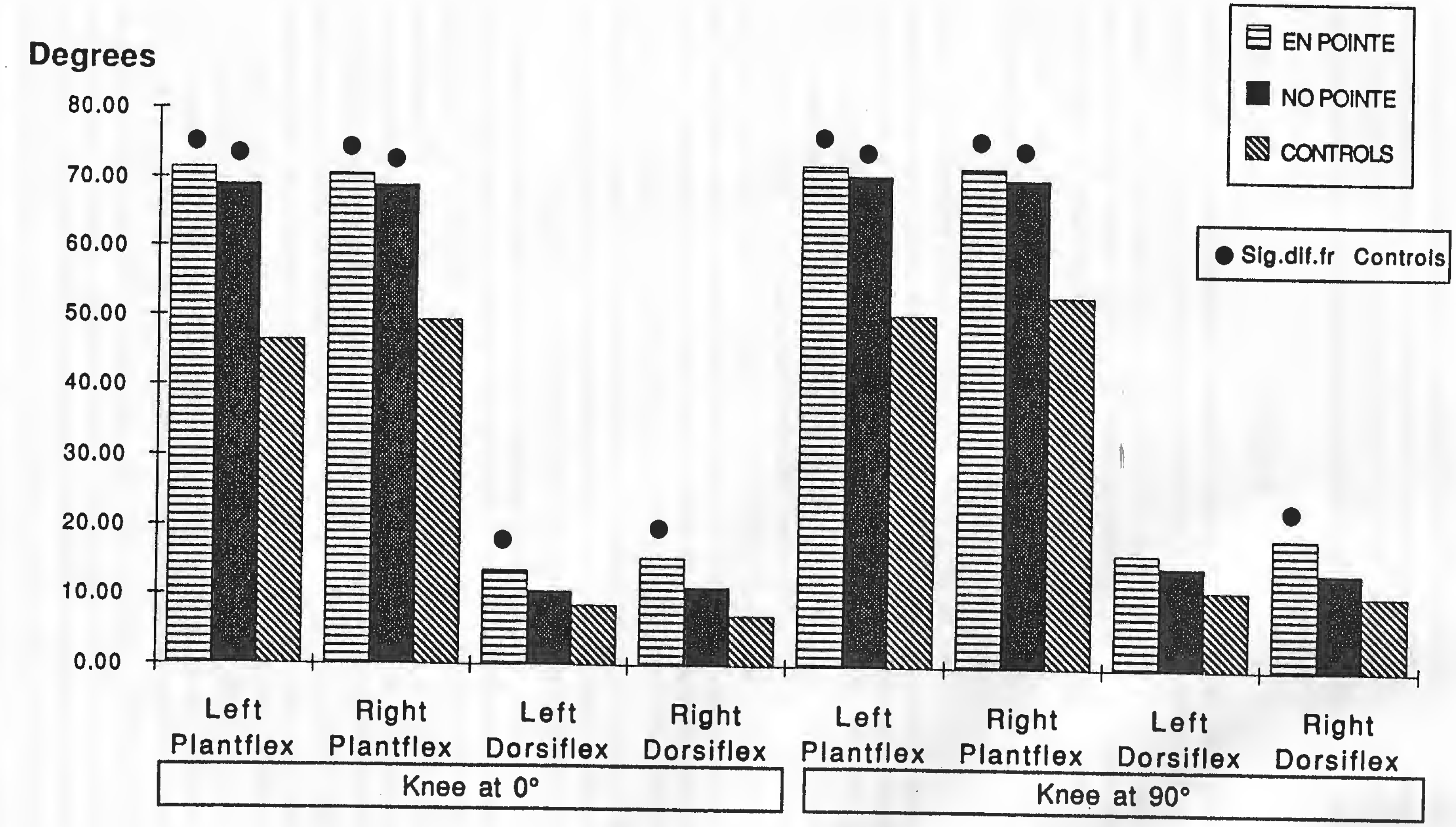

Figure 2. Ankle. Range of motion.

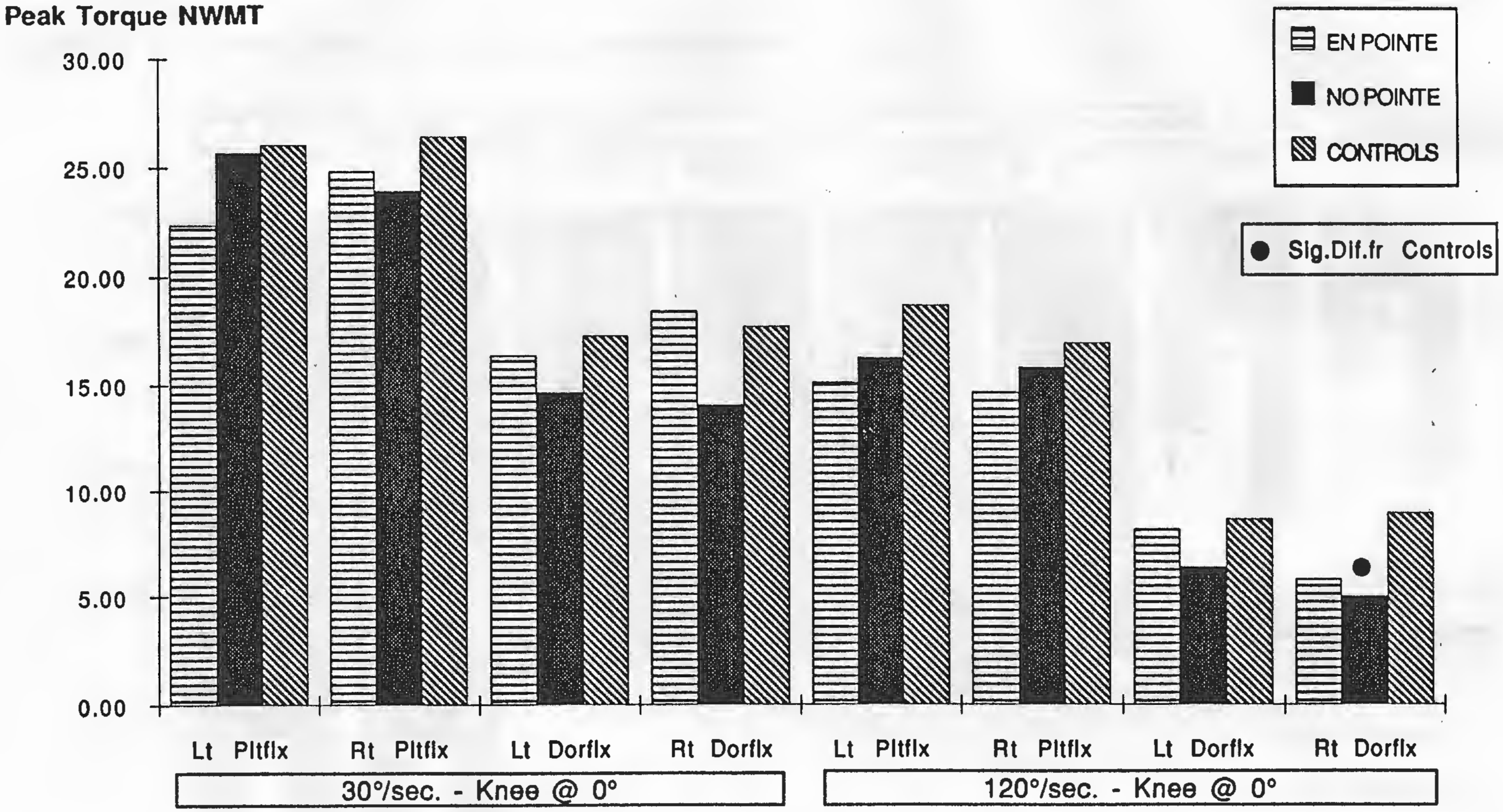

Figure 3. Peak torque. Ankle at 30°/second and 120°/second. Knee at 0°.

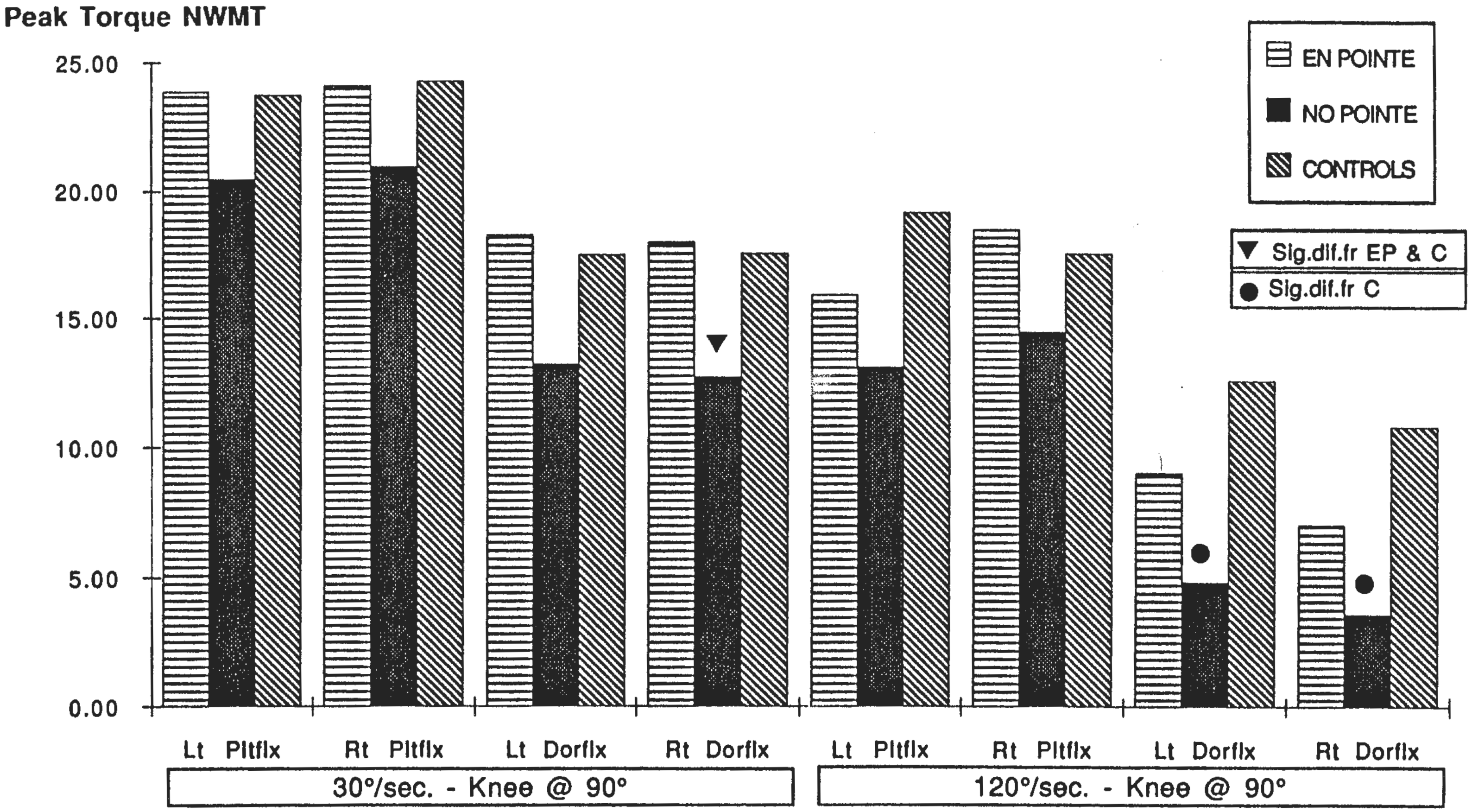

Figure 4. Peak torque. Ankle at 30°/second and 120°/second. Knee at 90°.

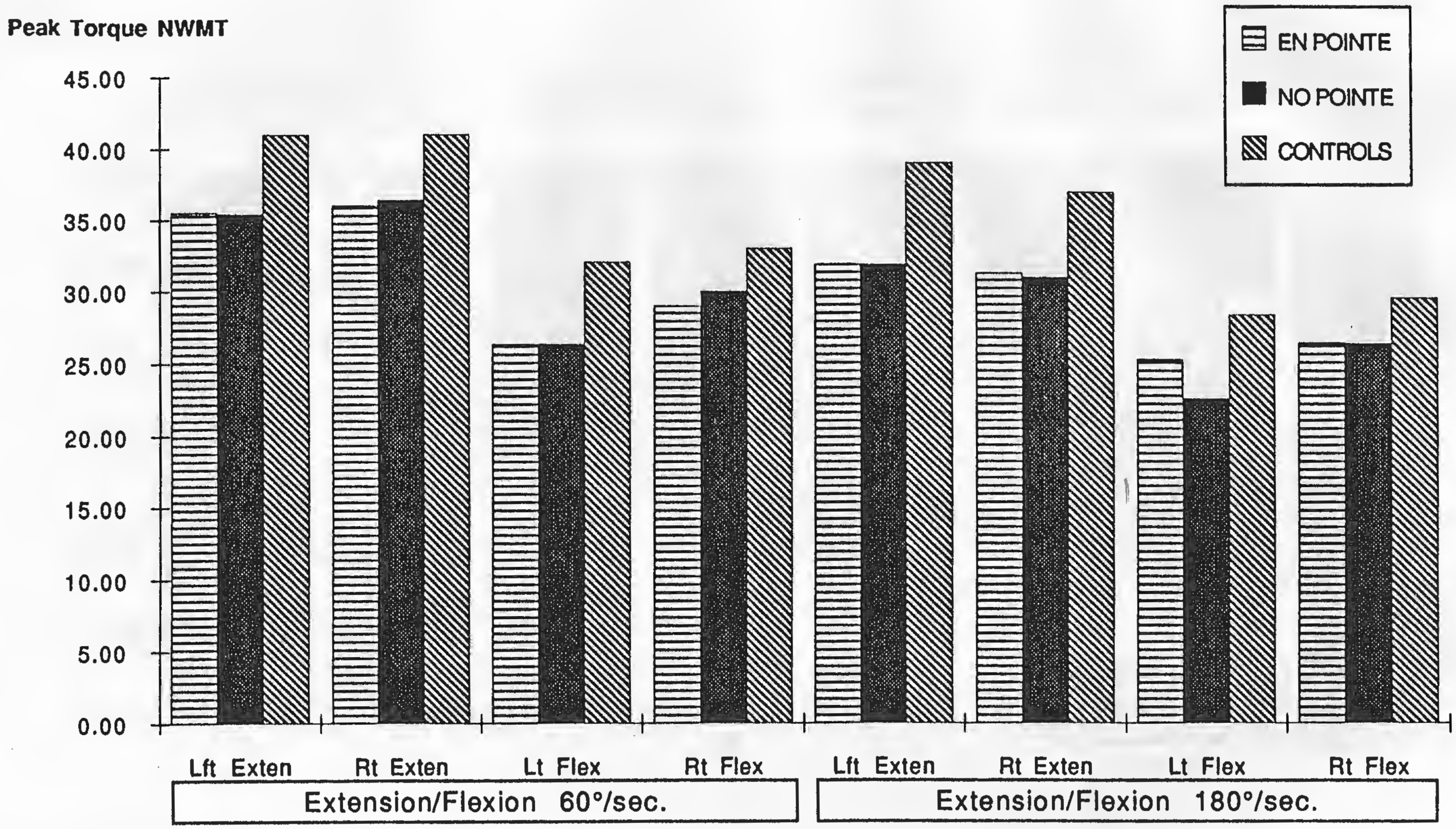

Figure 5. Peak torque. Knee at 60°/second and 180°/second.

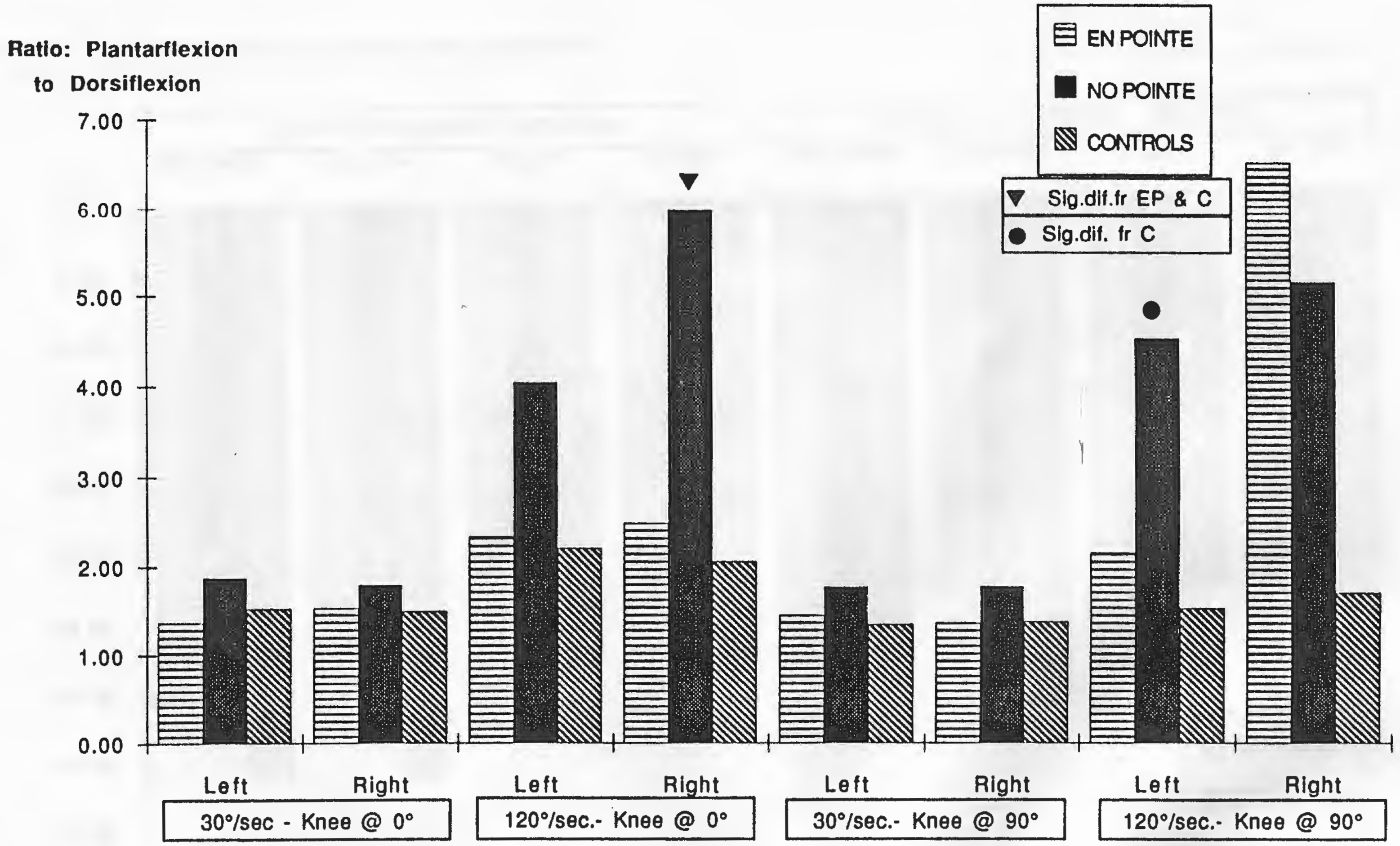

Figure 6. Ankle. Peak torque ratios.

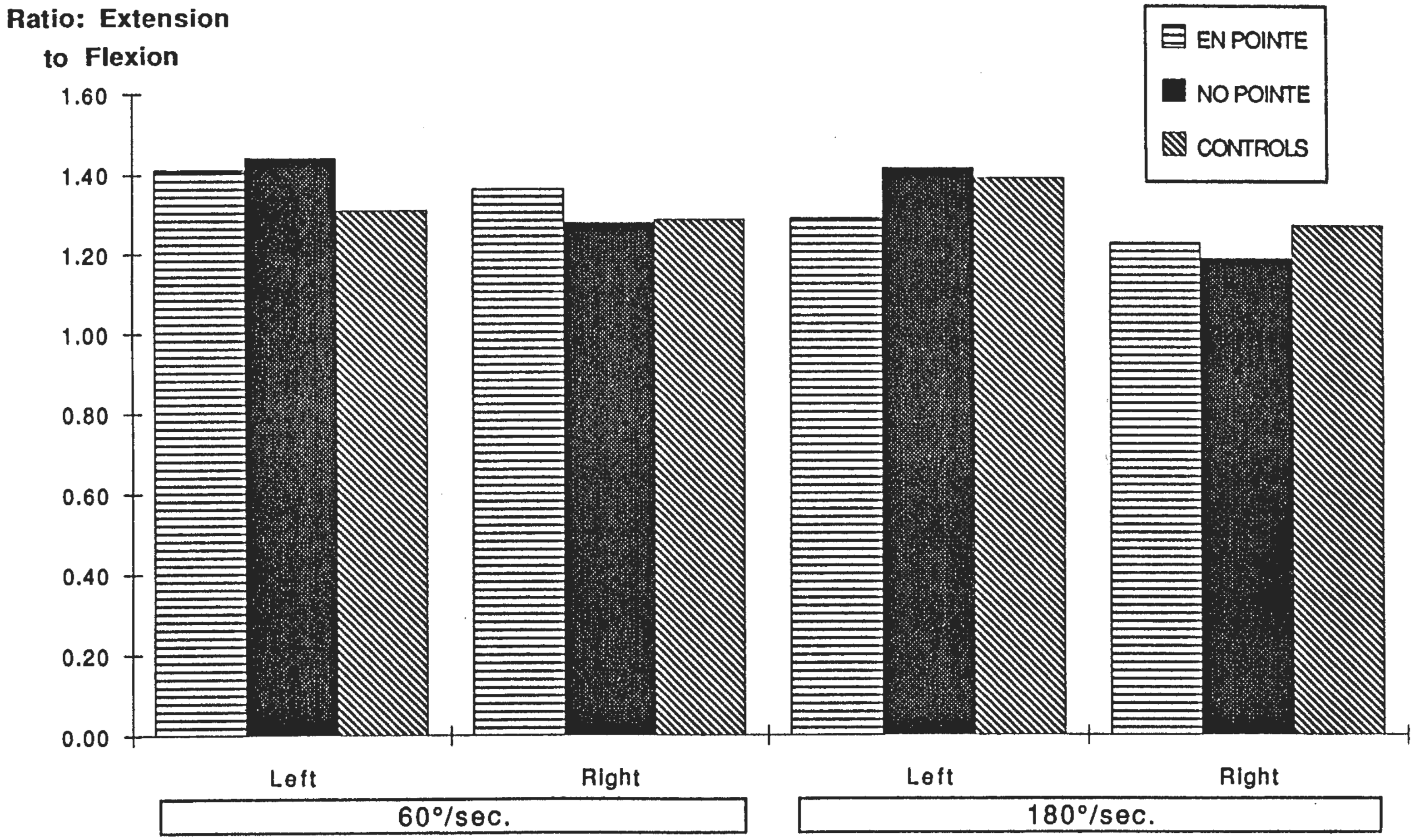

Figure 7. Knee. Peak torque ratios.

Discussion

The principal findings of this study are as follows: (a) Young women who have studied ballet demonstrate greater ROM at the ankle than do their peers with no ballet training; (b) conversely, when these groups are compared in their ability to generate peak torque in the major muscles of the lower extremities, the nondancers produce higher values; (c) ballet students with 1 year of pointe work tend to be marginally stronger, with slightly greater ROM, than those who have not yet progressed to dancing en pointe (perhaps because they also tend to be somewhat older). These findings raise interesting questions, both about the nature of the strength required to dance en pointe and about the appropriateness of the Cybex isokinetic dynamometer to measure that strength.

That dance training should increase ROM about the ankle surely comes as no surprise. Such staples of every ballet class as *demi-plié, grand-plié, relevé,* and the extension of relevé onto pointe, dorsiflex and plantarflex the muscles of the lower leg, ankle, and foot with greater frequency and through a wider range of motion than is normal for virtually any other activity. Hamilton et al. (1992) found a 78% greater than normal plantarflexion plus dorsiflexion ROM in the ballerinas they studied.

We encountered a number of clinical cases of young dancers having difficulty with pointe work. The difficulty was specifically related to a lack of ability to obtain the full pointe range of motion, in which the line of the foot becomes parallel to the line of the tibia (Figure 8a and 8b). One would assume, however, that this same frequency of use would also strengthen those muscles beyond the norm, an assumption that is at least anecdotally enhanced by the observation that most experienced dancers have noticeably well developed gastroc/soleus complex and quadriceps muscles—although there is some disagreement in the literature between those who find a significant correlation between calf circumference and peak torque capacity (Fugl-Meyer et al., 1980) and those who do not (Seymour & Bacharach, 1990). Why, then, did the nondancer control subjects in this study score higher on the strength tests than the dancer subjects, and how does this result affect the potential use of strength tests to determine readiness for pointe training? Some hypotheses follow:

First, the crossover between dancers and nondancers on the two types of tests administered in this study, the former scoring higher on ROM and lower on the strength tests, may reflect both the way muscle force is used in dorsiflexing and plantarflexing the foot, and the ability of a testing device like Cybex to measure that force at the muscles which generate it. Because of increased flexibility at the ankle, the dancer's foot describes a longer arc in moving from neutral (standing posture) to full dorsiflexion (grand-plié) or plantarflexion (en pointe) than the norm, thereby distributing the force required to perform the maneuver over a wider range of motion. By contrast, the nondancer's foot, traversing a shorter arc, delivers its force in a relatively concentrated fashion. This may translate for Cybex testing purposes into a higher peak torque. Thus, increased flexibility may be seen as having a negative impact on the ability to deliver high

Figure 8a. This mature adult female dancer has attained sufficient plantarflexion of the foot to align it with the tibia.

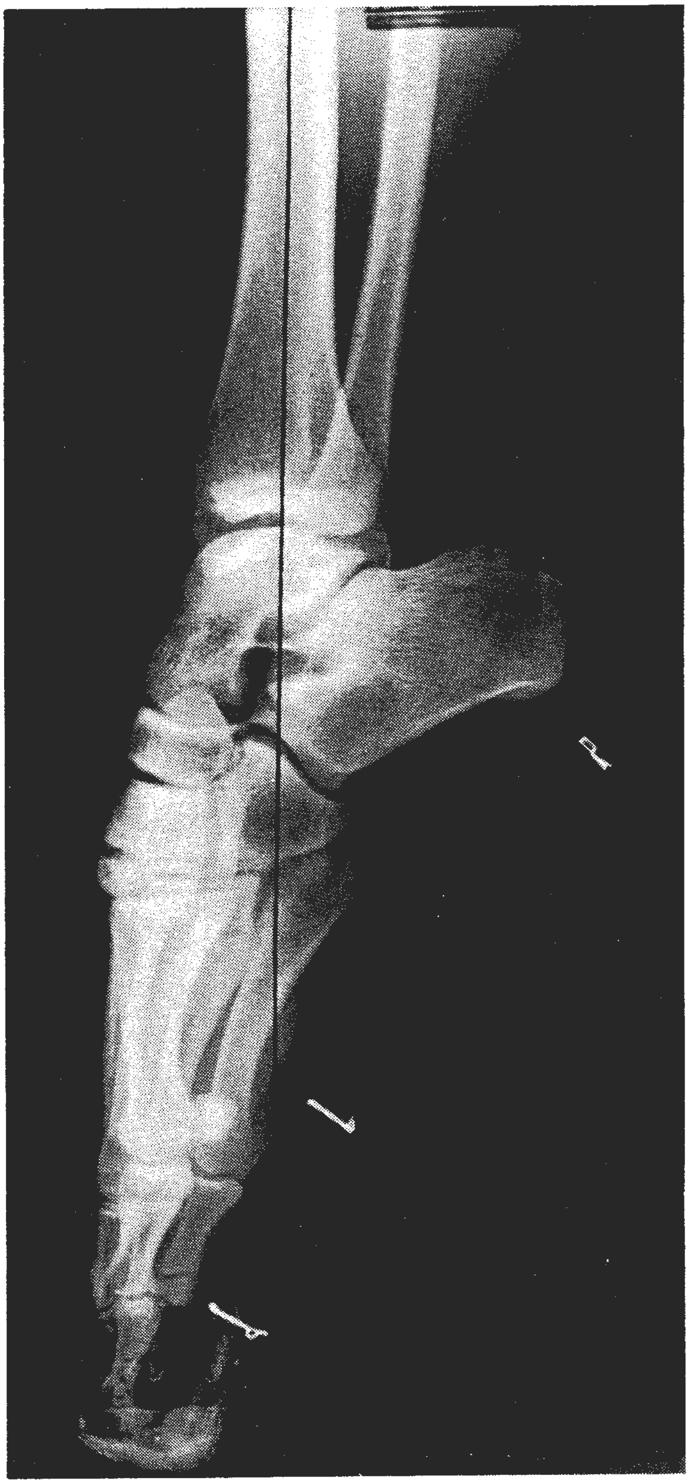

Figure 8b. This young dancer lacks full plantarflexion and has a series of lower extremity injuries, including knee and ankle pain.

peaks of tensile force. For the dance teacher who is trying to decide whether a student is strong enough to go on pointe, we might conclude, then, that it is more a question of integration of strength and flexibility than a standard definition of strength alone.

Second, in an even more basic way the Cybex testing may have distorted our view of the strength required to dance en pointe. The Cybex dynamometers are used to measure isokinetic strength, that is, the strength generated in *contracting* a muscle. Regarding the agonist-antagonist muscle groups tested in this study, most daily activities do draw heavily upon and thereby strengthen the contractile component of these muscles. What the Control group was manifesting, then, was a normal ability to produce peaks of contractual force in the plantarflexors and dorsiflexors. The kind of strength required by dancers, however, especially when performing such movements as going onto pointe from relevé, is more of an *eccentric* nature. For this reason, dancers are generally found (Micheli et al., 1984) to have far greater imbalances of plantarflexors to dorsiflexors and extensors to flexors than the population at large (though this observation is supported in the current study only by the NP ratios at the ankle). Therefore it seems probable that the type of strength tested here is not an accurate indicator of a student's readiness to dance en pointe.

Third, it is even possible that the muscle groups tested do not constitute an adequate indicator of the strength required to dance en pointe. The large muscle groups of the upper leg that flex and extend the lower leg, and those of the lower leg that dorsiflex and plantarflex the foot, are certainly the controlling factors in the performance of many daily activities. But in the delicate maneuver involved in moving from the whole foot onto relevé and from there onto pointe, it is highly probable that the intrinsic muscles of the foot play an even more crucial role. In this respect, the higher strength values achieved by the Control group seem only partially relevant, as they leave out an important factor in the equation. At present Cybex does not have a tester for the intrinsic foot muscles, although inverter/everter strength can be measured (Karnofel, Wilkinson, & Lentell, 1989; Lentell, Cashman, Shiomoto, & Spry, 1988; Wong, Grasheen-Wray, & Andrews, 1984). As these muscles may provide essential ankle control and stability in relevé and en pointe work, inversion and eversion testing should be done in the future.

Finally, a more relevant musculotendinous component for pointe work may well be progressive increase in muscle endurance. As mentioned in the Methods section, there was an endurance aspect to the Cybex testing undertaken for this study which is not reported on here. The decision not to use that material was based in part on the realization that, because it is anaerobic even in its training regimen, ballet really does not require the kind of strength that can be measured in increments of endurance (rather, the ballet dancer must be able to produce strength through the entire ROM). However, there was also something in the data themselves that influenced this decision. Typically, the graph of energy expended on a Cybex test declines from a high point of available force in the early repetitions of a test bout to a low point (sometimes failure) near the end, as the subject fatigues. Endurance is of course measured by the slope and extent of that decline. In a surprising number of test bouts for this study, quite a different pattern emerged: the peak torque was actually found at or near the end of the bout, causing a negative fatigue result.

The reason for this would seem to be that, despite adherence to the standard procedure of allowing several pretest repetitions for the subjects to experience the degree of difficulty involved, and the tester's encouragement to give their best effort on each repetition, many of our subjects were in effect "feeling their way into the tests," that is, saving their strength to make sure they would get to the end of each bout. One might explain this behavior on the part of the dancers as protectiveness of their lower extremities, or perhaps as excessive concern with technical correctness; however, one would have expected a less inhibited approach from the Controls. In actuality, the Controls produced the suspect pattern more than twice as often as the combined groups of dancers. Thus we are left with yet another reason for questioning the reliability, for our purposes, of the Cybex dynamometer—which is not necessarily to doubt the general reliability of this kind of testing, a subject that has been analyzed extensively with positive results for the most part (Burdett & Swearinger, 1987; Francis & Hoobler, 1987; Karnofel et al., 1989; Manning, Dooly-Manning, & Perrin, 1988; Montgomery, Douglass, & Denster, 1989; Murray, Harrison, & Wood, 1982; Nosse, 1982; Perrin, 1986; Thigpen, Blinke, & Lang, 1990; Wennerberg, 1991; Wilkie, Johnson, & Levine, 1987).

Conclusion

The problem of putting a quantitative base under the assessment of a ballet student's readiness for pointe work turns out to be a complex one. Attaining sufficient range of motion to plantarflex the foot in a line parallel to the line of the tibia (Figures 8a and 8b) appears to be essential in order to progress to en pointe training. This indeed may be a much more important physiological determinant than strength. The ballet teacher's judgment in this matter apparently must encompass more than standard measures of lower extremity strength; the EP subjects in this study *were* somewhat stronger than those not yet on pointe, but they were weaker than the normative controls for their age. Probably the ability to exercise muscular control over a greater than normal range of motion is a more important criterion. In applying such criteria the teacher may instinctively take into account important strength parameters—for example of the intrinsic foot muscles—that do not readily lend themselves to measurement at this time. This study was unable to identify exactly what these parameters are, but it shows that Cybex testing of the flexion-extension muscles at the knee and ankle is not in itself the appropriate tool for determining when a young woman is ready to dance en pointe.

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Acknowledgments

The authors gratefully acknowledge physical therapists Barbara Capone for doing the Cybex testing and Kathleen Richards and Arleen Walaszek for their assistance in this area. Jim Mulherin provided the data analysis consultation. We are especially appreciative of John Solomon's editorial contribution to this manuscript. The project was supported in part by the Children's Sports Medicine Foundation, Boston, and the University of California, Santa Cruz.