Electromyographic analysis of grand-plié in ballet and modern dancers

ELLY TREPMAN, RICHARD E. GELLMAN, LYLE J. MICHELI, and CARLO J. DE LUCA

The NeuroMuscular Research Center, Boston University, Boston, MA; Boston Foot and Ankle Center, New England Baptist Hospital, Boston, MA; and Division of Sports Medicine, Harvard Medical School and Children's Hospital, Boston, MA

ABSTRACT

TREPMAN, E., R. E. GELLMAN, L. J. MICHELI, and C. J. DE LUCA. Electromyographic analysis of grand-plié in ballet and modern dancers. *Med. Sci. Sports Exerc.*, Vol. 30, No. 12, pp. 1708–1720, 1998. **Purpose:** The purpose of this report is to describe lower extremity muscle activity in grand-plié, as determined by EMG analysis; to compare and contrast muscle function in grand-plié and demi-plié to support the hypothesis that grand-plié is not simply a deeper demi-plié, but rather a fundamentally different movement in terms of muscle use; and to present further evidence in support of the hypothesis that ballet dancers use muscles differently than modern dancers in dance movement. **Methods:** Surface electromyography was used to analyze lower extremity muscle activity during grand-plié in first position with lower extremities turned out in five ballet and seven modern female professional dancers. **Results:** Electromyographic (EMG) activity of tibialis anterior included continuous activity from heel-off during the lowering phase, through midcycle, and ending at heel-on during the rising phase in all grand-pliés; the majority of tibialis anterior EMG tracings in ballet dancers had additional activity at the end of the rising phase. All EMG tracings for vastus lateralis and medialis included a peak of activity during the lowering phase, a *decrease* (valley) at midcycle, followed by another peak during the rising phase; increased activity at the end of the rising phase was observed in most grand-pliés in ballet, and not modern, dancers. Adductor EMG activity was also observed in all tracings with a peak during the lowering phase from heel-off to midcycle, a valley at midcycle, followed by a peak of activity in early rising phase; the midcycle valley was of lower, and the rising phase peak of higher, activity in ballet compared with modern dancers. Variation of EMG patterns was observed for lateral and medial gastrocnemius, gluteus maximus, and hamstrings. **Conclusions:** The data support the concept that lower extremity muscle activity in dance movement is comprised of three major types: (a) unique, characteristic activity required for the execution of the movement; (b) varied activity which is characteristic of dancers of different dance idioms; and (c) varied activity which may depend on factors such as balance, personal habit, and individual training background. Furthermore, EMG activity of vastus lateralis and medialis at the midcycle valley in grand-plié was significantly less in ballet dancers than in modern dancers despite similar degree of knee flexion, suggesting that ballet dancers may have lower patellofemoral joint reaction force at midcycle than modern dancers. **Key Words:** ELECTROMYOGRAPHY, DANCE, MOTION ANALYSIS

Interest in the analysis of dance motion has been evident in studies of human movement for over a century (16). However, electromyographic (EMG) techniques have only recently been used to document and study the way dancers use their muscles to perform esthetically beautiful movements with grace, achieving an illusion of effortlessness despite the intense physical demands of the movement (2–5,8,21,23,25,26). The characterization of EMG activity in dance movement may be of practical use in the selection of movements and directed exercises in injury rehabilitation or in the preparation of the dancer for performance of an unfamiliar choreographic style requiring previously under-emphasized muscles.

0195-9131/98/3012-1708$3.00/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

Submitted for publication November 1995.
Accepted for publication May 1998.

The training of dancers includes emphasis on proficiency in basic movements (15). The most fundamental of these movements is the plié, in which the upright torso, spine, and pelvis are stabilized as they are lowered with coordinated hip and knee flexion, and then raised back to the starting position with hip and knee extension (9). The repetitive execution of the plié in training class is used to improve strength, timing, alignment, trunk stability, and coordination of joint movement (9). Furthermore, the plié is often the first component of other movements such as relevé (rising on the toes), pirouettes (twirls of the body), and jumps (15).

In demi-plié, the lowering and rising of the upright torso is performed as the foot remains flat on the floor throughout the movement (26). In grand-plié, the lowering of the upright torso is performed as the heel is raised from the floor and the metatarsophalangeal joints are dorsiflexed, and the entire body weight is borne by the metatarsal head region and toes. Compared with the demi-plié, the grand-plié is intrinsically more difficult to perform because of the requirement of balance and torso stability on the smaller base of support and the lower position of the torso at midcycle in grand-plié. Therefore, the grand-plié is believed to be important in the development of strength, flexibility, and balance (6), but it is an advanced exercise that may potentially be executed with technical faults (11).

There is controversy among dance instructors regarding the continued use of grand-plié in training class because of differences in opinion about the risks and benefits of this exercise. It has been suggested that the traditional early use of grand-plié in the dancer's training may be hazardous because of the great degree of knee flexion that may result in large patellofemoral forces and knee injury (4,5) and because improper execution may result in malalignment and increased stresses in the hallux, foot, ankle, knee, thigh, hip, pelvis, spine, and torso, contributing to injury (6,17). As a result, some dance instructors have reduced emphasis on early introduction of grand-plié until later in training, after a technically satisfactory demi-plié has been learned, and others have excluded grand-plié altogether, attempting to replace it with other exercises that accomplish similar goals (6). In contrast, it has been argued that grand-plié is not harmful if performed by the more advanced student with moderation and with careful emphasis on technique and lower extremity alignment and that the exercise may be of value at the beginning of the dance class in stretching the lower extremity muscles and improving body placement and coordination with the lower extremities turned out (11).

Anatomic concepts of dance training and injury rehabilitation have been based on qualitative images of muscle function in dance movement. However, observed EMG activity in dancers may be inconsistent with descriptive models (23,26). The absence of adductor EMG activity during the rising phase of 42% of demi-pliés (26) contradicted previous hypothetical models of demi-plié that had proposed the necessity of continuous adductor activity during the rising phase (14). Thus, EMG analysis refuted the previous dictum that demi-plié is a reliable exercise to strengthen the adductors (26). Therefore, replacement of an exercise such as grand-plié may be based on theoretical models that may be anatomically inaccurate. If an instructor excludes grand-plié from a training program, it may be important to know what muscle groups should be emphasized in the substitute exercises. However, only limited EMG information regarding grand-plié is available (4,5).

The purpose of this report is to describe lower extremity muscle activity in grand-plié, as determined by EMG analysis; to compare and contrast muscle function in grand-plié and demi-plié to support the hypothesis that grand-plié is not simply a deeper demi-plié, but rather a fundamentally different movement in terms of muscle use; and to present further evidence in support of the hypothesis that ballet dancers use muscles differently than modern dancers in dance movement.

MATERIALS AND METHODS

Subjects and electromyographic (EMG) arrangement. Dancer population, EMG arrangement, position of subjects, and data collection was identical to that previously reported (26). The grand-pliés were performed immediately after the standing posture repetitions and demi-pliés reported previously (26) during the same recording session without any change in subject or electrode position; this enabled direct comparison between EMG data for grand-plié with those of standing posture and demi-plié (26).

The five ballet (Boston Ballet Company) and seven modern (Concert Dance Company and other local Boston companies) female professional dancers who volunteered for the study were of similar height, weight, and dance experience, except that the modern were currently involved in significantly less ballet activity than ballet dancers (26). EMG data were collected using parallel bar active surface electrodes (NeuroMuscular Research Center, Boston University, Boston, MA) placed over the right lateral gastrocnemius, medial gastrocnemius, tibialis anterior, vastus lateralis, vastus medialis, gluteus maximus, hamstrings, and adductors as previously described (26). Raw EMG signals were amplified (20–400 Hz) and sampled at 1 kHz using data collection software (Watscope, Northern Digital Inc., Waterloo, Ontario).

All movements were performed with the dancers in classical first position (anatomic position with lower extremities laterally rotated and heels together). Each dancer selected her own comfortable maximum amount of lower extremity lateral rotation (turnout), which varied from subject to subject (26). Turnout remained constant for each individual dancer for all repetitions of all movements studied using an outline drawing of the feet prepared and taped to the floor at the beginning of the session, which served as a reference for placement of the feet (26). Turnout was quantitated as the angle between lines drawn from the second toe to the middle of the heel (26).

Videotaping protocol and measurement of joint range of motion and torso sway for grand-plié were identical to those for demi-plié (26) except that for grand-plié additional measurements were made of left first metatarsophalangeal (MP) joint dorsiflexion from the videotape view 45° oblique to the dancer. First MP joint dorsiflexion was measured as the angle between two lines, one along the plantar aspect of the foot from the heel to the first MP joint region and another along the longitudinal axis of the great toe.

Grand-plié. For description and analysis of grand-plié, we defined the grand-plié cycle as consisting of two phases: (i) the lowering phase, during which the torso is lowered, and (ii) the rising phase, in which the torso rises back to the starting, upright position (Fig. 1). The instant at which the torso is lowest, with the hips and knees at maximum flexion, was defined as the midcycle period. The instant during the lowering phase at which the heel rises off the floor was defined as heel-off; that during the rising phase at which heel contact with the floor is restored was defined as heel-on.

The lowering phase was subdivided into two component periods separated by heel-off: (a) early lowering phase, from start to heel-off, during which both the forefoot and heel remain in contact with the floor; and (b) late lowering phase, from heel-off to midcycle, during which the heel rises with

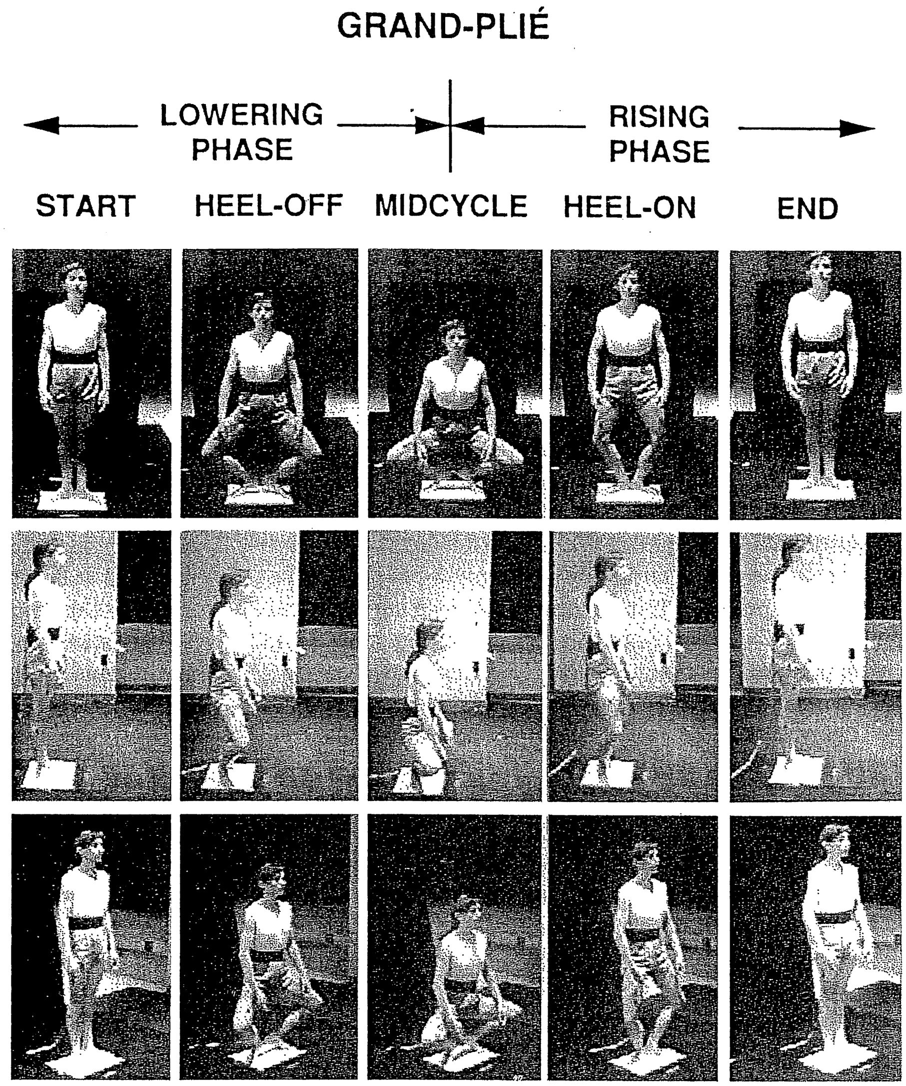

Figure 1—Ballet dancer performing grand-plié in classical first position (turned out), as seen from front (*top row*), side (*middle row*), and oblique (*bottom row*) views. The dancer is positioned upright just before the start of grand-plié (*first column*), proceeds through the lowering phase heel-off (*second column*) to midcycle (*third column*), and then through rising phase heel-on (*fourth column*) to completion of the movement at the end of rising phase (*fifth column*).

progressive MP joint dorsiflexion and body weight is borne entirely by the toes and metatarsal head region. The rising phase was subdivided into two component periods separated by heel-on: (a) early rising phase, from midcycle to heel-on, during which the heel is progressively lowered; and (b) late rising phase, from heel-on to end, during which both forefoot and heel are in contact with the floor.

The dancers performed an 8-s grand-plié (five repetitions), timed to a count announced by an assistant using a stopwatch so that the lowering and rising phases were each 4 s. With the dancer in standing first position ready to start, announcement at 1-s intervals was commenced 2 s before beginning the grand-plié movement so that she would be ready to start at the desired time. EMG activity was recorded beginning at time = 0 s, 1 s before onset of the grand-plié, and continued 1 s after completion of the movement (total recording interval 10 s). The anteroposterior videotape view was recorded for the first and fourth grand-plié repetitions, the lateral view for the second and fifth repetitions, and the oblique view for the third repetition (26). Upper extremity position and movement during grand-plié was restricted to ballet first and second position port de bras (15).

Data analysis. EMG data were processed to calculate root-mean-square (RMS) voltage for 0.10-s intervals, and plotted against time as previously described (1,26).

Grand-plié EMG plots were analyzed two different ways. First, plots were classified into patterns based on the appearance of the waveform for the entire grand-plié. Plot patterns of similar major features were then grouped together into categories (types) on the basis of whether EMG activity was greatest at midcycle or the other four component periods.

Second, each plot was graded for presence or absence of increased EMG activity above baseline in each component period. It was established from first MP joint motion data that heel-rise occurred at approximately recording time = 2 s (i.e., 1 s after start of the movement) and heel-on at recording time = 8 s (i.e., 1 s before end) (see *Results*). Therefore, each EMG plot was subdivided as follows: start to heel-off (EMG recording time 1–2 s), heel-off to midcycle (2–5 s), midcycle (5 s), midcycle to heel-on (5–8 s), and heel-on to end (8–9 s). Baseline activity was determined using RMS voltage plots during standing posture as reported previously (26).

TABLE 1. Height and joint angles at midcycle of demi-plié and grand-plié in ballet and modern dancers.

	Demi-plié: Midcycle (t = 4 s)				Grand-plié: Midcycle (t = 5 s)				Demi-plié vs Grand-plié
	Ballet	Modern	Total	t, P[a]	Ballet	Modern	Total	t, P[a]	t, P[b]
Height (t)/standing height	0.92 ± 0.02	0.94 ± 0.02	0.93 ± 0.02	NS	0.68 ± 0.04	0.70 ± 0.04	0.69 ± 0.04	NS	18.11, 0.0001
Hip abduction (deg)	21 ± 7	13 ± 5	17 ± 7	NS	72 ± 6	61 ± 8	66 ± 9	2.60, 0.03	14.93, 0.0001
Hip flexion (deg)	22 ± 3	27 ± 7	25 ± 6	NS[c]	24 ± 7	46 ± 12	36 ± 15	3.61, 0.005	2.20, 0.04[c]
Knee flexion (deg)	70 ± 3	61 ± 6	64 ± 7	3.17, 0.01	139 ± 12	142 ± 8	141 ± 10	NS	22.62, 0.0001
Ankle dorsiflexion (deg)	45 ± 2	40 ± 5	42 ± 5	NS	25 ± 9	25 ± 10	25 ± 9	NS	5.73, 0.0001
First MP dorsiflexion (deg)	0 ± 0	0 ± 0	0 ± 0	NS	41 ± 11	49 ± 9	46 ± 11	NS	15.01, 0.0001

N = 12 demi-pliés and 12 grand-pliés (all dancers), 5 each for ballet, 7 each for modern dancers.
[a] Comparison between ballet and modern groups: Student's t-test, df = 10; NS (not significant): t < 2.23, P > 0.05, except for hip flexion.
[b] Comparison between demi-plié and grand-plié (all dancers): Student's t-test, df = 22; NS (not significant): t < 2.07, P > 0.05, except for hip flexion.
[c] Hip flexion: Demi-plié: ballet vs modern comparison, df = 8; NS (not significant): t < 2.31, P > 0.05; All dancers: demi-plié vs grand-plié comparison, df = 20; NS (not significant): t < 2.09, P > 0.05 (data for two ballet dancers not available in demi-plié because videotape views oblique, not true lateral).

Further characterization of the EMG tracings for quadriceps and tibialis anterior was performed by determining ratios of RMS voltage from one part of a tracing to another. Peak maximum for vastus lateralis and medialis during the lowering and rising phase peaks (see *Results*) occurred at different time points during different grand-pliés. The lowering phase peak was broad (see *Results*), making it difficult to select a single maximum voltage point; therefore, RMS voltage at peak maximum for the lowering phase peak was determined as the largest average of five consecutive RMS voltage values at the peak. In contrast, the rising phase peak maximum was usually discrete (see *Results*); therefore, RMS voltage at peak maximum for the rising phase peak was determined as the single maximum RMS voltage value. RMS voltage for vastus lateralis and medialis at midcycle valley was determined as the minimum RMS voltage at midcycle before onset of the rising phase. Ratios of vastus lateralis and medialis RMS voltage were then calculated to directly compare average peak RMS voltage maximum in the lowering phase, peak maximum in the rising phase, and midcycle valley minimum for each grand-plié. For tibialis anterior, RMS voltage at midcycle was determined as the average of five consecutive RMS voltage values at midcycle.

For comparison of the relative amount of muscle activity between different dance movements, EMG data during grand-plié were directly compared with that during standing posture and demi-plié performed during the same recording session without any change in electrode position (26). For demi-plié, tibialis anterior RMS voltage at midcycle was defined by the peak maximum just before the drop in EMG activity to zero at the start of the rising phase (26); midcycle peak RMS voltage for vastus lateralis and medialis was determined as the average of the five consecutive RMS voltage values centered around the midcycle time point defined by the tibialis anterior midcycle peak. For standing posture, baseline RMS voltage for vastus lateralis, vastus medialis, and tibialis anterior was determined as the average RMS voltage of all time points of 4-s standing repetitions in which the EMG tracing had been labeled as baseline (26). Ratios were then calculated between these peak, valley, midcycle, and baseline RMS voltage values to determine the relative magnitude of EMG activity between components of grand-plié, demi-plié, and standing posture for quadriceps and tibialis anterior.

Height, joint angles, and sway data are reported as mean ± SD unless otherwise indicated. Statistical analysis was performed for average values using two-tailed Student's t-test, and for enumeration data using chi-square (χ^2) test. Height and joint range of motion against time was analyzed using two-way ANOVA with one repeated measure, with dancer group as the between factor and time the within factor. The relation between joint angle at midcycle and turnout angle was evaluated using simple regression analysis. Level of significance for all analyses was defined by $P \leq 0.05$.

RESULTS

Videotape observations and goniometric analysis. In comparison with demi-plié, grand-plié consisted of more marked lowering of the torso, with four-fold greater decrease in body height at midcycle; this was accomplished with significantly greater hip abduction and knee flexion and less ankle dorsiflexion for all dancers (Table 1). Hip flexion at midcycle was also significantly greater in grand-plié than demi-plié in the modern dancers (df = 12, t = 3.58, P = 0.004) (Table 1), who had positioned themselves with less turnout than the ballet dancers (26). For grand-plié, simple regression analysis revealed a significant negative correlation between turnout angle (x) and hip flexion at midcycle (y), defined by the equation: y (degrees) = 102–0.64 x (degrees) (N = 12, r = 0.704, r^2 = 0.496, F = 9.85, P = 0.01). In grand-plié, hip abduction at midcycle was significantly greater and hip flexion less in ballet than in modern dancers; midcycle hip flexion in grand-plié for ballet dancers was similar to that for demi-plié (Table 1). First MP joint dorsiflexion, which does not occur in demi-plié, began in grand-plié 1 s after starting the movement, when the lowering of body height had not yet reached the nadir achieved in demi-plié (26), and ended with heel-on 1 s before completion of grand-plié, when the body was almost fully upright (Fig. 2).

For grand-plié, two-way ANOVA with one repeated measure revealed statistically significant differences between ballet and modern dancer groups for height against time (df = 1, F = 5.79, P = 0.037) and hip flexion against time (df = 1, F = 15.69, P = 0.003) (Fig. 2). Student's t-test at each time point showed that the difference between ballet and modern dancers in height against time during grand-plié

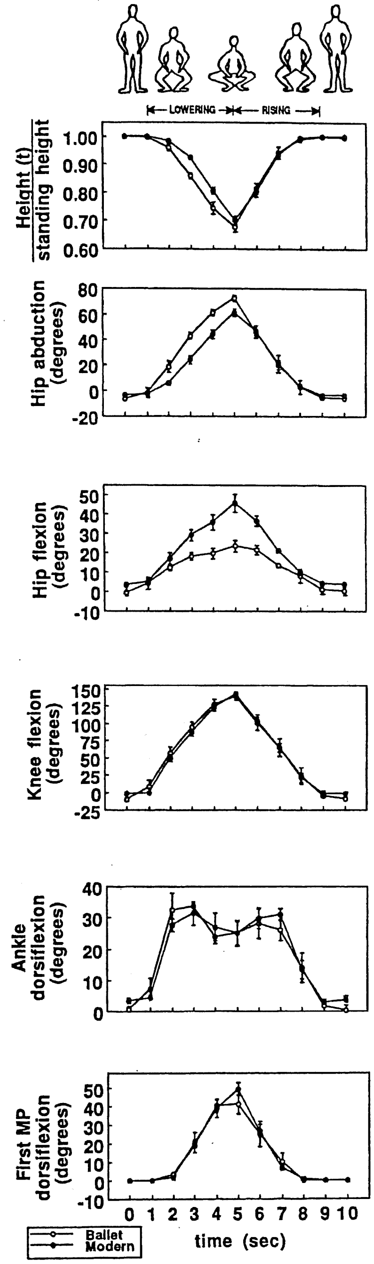

Figure 2—Height and lower extremity joint range of motion during grand-plié in ballet and modern dancers. EMG recording was started at time = 0 s and completed at 10 s. The dancers were instructed to start the grand-plié at time = 1 s, reach midcycle at 5 s, and complete the movement at 9 s; the lowering and rising phases were each 4 s in duration. Height data were normalized to standing height. Plotted values are average ± SE of the mean for the five ballet (○) and seven modern (●) dancers; when not visible, error bars are smaller than the points.

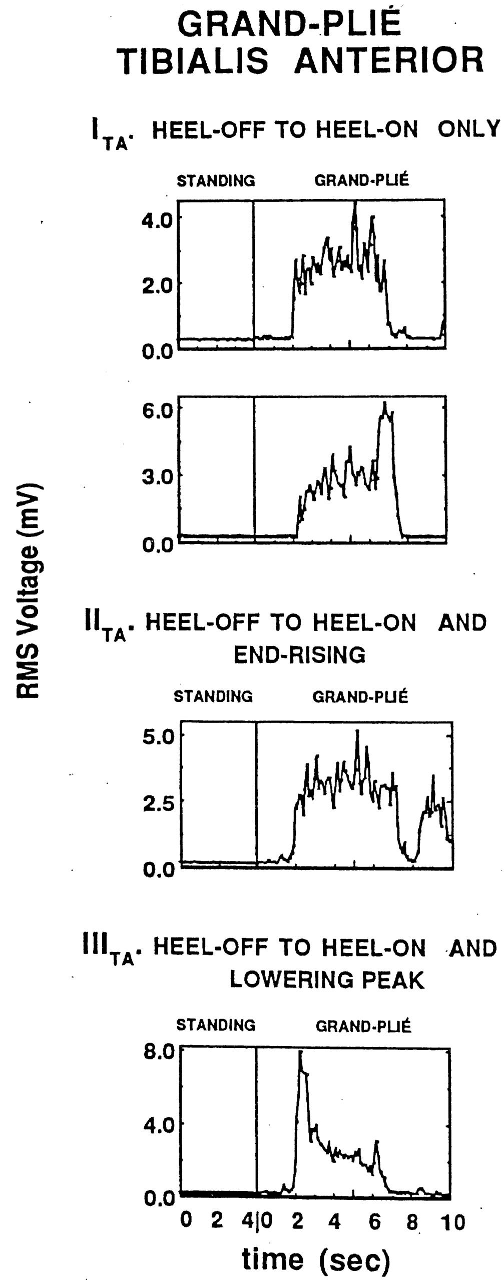

Figure 3—Surface electromyography of tibialis anterior during grand-plié. Representative plots of RMS voltage against time during grand-plié are demonstrated adjacent to one of the standing posture EMG plots for the same dancer. EMG activity from heel-off (lowering phase) through heel-on (rising phase) was observed in all 60 grand-plié repetitions. Type I_{TA} plots had activity from midcycle to heel-on (rising phase) greater than heel-off to midcycle (lowering phase); type II_{TA} plots had an additional peak of activity at the end of the rising phase; and type III_{TA} plots had a peak of activity during the lowering phase.

occurred because of more rapid lowering by the ballet dancers during heel-off to midcycle period (Fig. 2), with significantly lower normalized height at 2, 3, and 4 s ($P < 0.02$); there was no difference between ballet and modern dancers in normalized height at midcycle ($df = 10$, t = 1.08, $P = 0.30$) or during the rising phase. Hip flexion was significantly less in ballet than modern dancers at 0, 3, 4, 5, 6, and 7 s ($P < 0.04$). There was no significant difference (two-way ANOVA) between ballet and modern dancers in hip abduction ($df = 1$, $F = 3.83$, $P = 0.08$), knee flexion ($df = 1$, $F = 0.003$, $P = 0.96$), ankle dorsiflexion ($df = 1$, $F = 0.07$, $P = 0.80$), or first MP dorsiflexion ($df = 1$, $F = 0.096$, $P = 0.76$) against time (Fig. 2). However, genu recurvatum was greater in ballet than modern dancers both at the start (time = 0 s, ballet knee flexion $-10 \pm 5°$, modern $-1 \pm 1°$, $df = 10$, t = 4.31, $P = 0.002$) and completion (time = 10 s, ballet knee flexion $-9 \pm 7°$, modern $-1 \pm 2°$, $df = 10$, t = 2.70, $P = 0.02$) of grand-plié.

TABLE 2. EMG activity in tibialis anterior during grand-plié: number (percent) of EMG tracing types.[a]

	Ballet	Modern	Total
I_{TA}	5 (20%)	26 (74%)	31 (52%)
II_{TA}	17 (68%)	2 (6%)	19 (32%)
III_{TA}	3 (12%)	7 (20%)	10 (16%)
χ^2, $P <$ [b]		26.74, 0.001	

[a] Tibialis anterior: $N = 60$ (total), 25 (ballet), 35 (modern).
[b] Comparison between ballet and modern dancers, $df = 2$; NS (not significant): $\chi^2 < 5.99$, $P > 0.05$.

When grand-plié was viewed from the side, the torso was noted to sway forward during the lowering phase and backward during the rising phase (Fig. 1). Measurement of torso sway from the videotape confirmed that in almost all dancers torso sway was forward during the lowering phase (average 3.3 ± 1.9 cm; range 0.0 cm to 7.0 cm) and backward during the rising phase (average 2.7 ± 1.8 cm; range 0.0 to 7.0 cm). Forward sway during the lowering phase was significantly greater for grand-plié than demi-plié (26) (all dancers: $df = 31$, $t = 2.30$, $P = 0.03$), but the difference in backward sway between the two movements was not significant ($df = 30$, $t = 1.92$, $P = 0.06$).

Electromyographic (EMG) analysis of grand-plié: patterns of activity. In the 60 repetitions of grand-plié analyzed, there was little variation in EMG tracings from the tibialis anterior, vastus lateralis, vastus medialis, and adductor electrodes. In contrast, the other four muscles tested were characterized by heterogeneity of EMG activity.

Tibialis anterior. Tibialis anterior EMG activity from heel-off through heel-on was observed in all 60 grand-plié repetitions (Fig. 3). The EMG tracings for tibialis anterior were classified on the basis of three distinguishing features: I_{TA}, activity from midcycle to heel-on (rising phase) greater than heel-off to midcycle (lowering phase); II_{TA}, an additional peak of activity at the end of the rising phase; and III_{TA}, a peak of activity during the lowering phase (Fig. 3). Ballet and modern dancers differed significantly in tibialis anterior activity; ballet dancers had a peak of tibialis anterior activity at the end of the rising phase (II_{TA}) in the majority of grand-pliés, whereas modern dancers did not (I_{TA}) (difference between ballet and modern dancers: $df = 2$, $\chi^2 = 26.74$, $P < 0.001$) (Table 2).

Vastus lateralis and medialis. All grand-pliés had a broad lowering phase peak of activity in vastus lateralis and medialis and a decrease in activity (valley) at midcycle, followed by a rising phase peak with maximum activity during the early part of the rising phase (Fig. 4). The rising phase peak was of greater maximum voltage than the lowering for both muscles in all 60 grand-pliés.

The EMG tracings for the vastus lateralis and medialis were classified on the basis of two characteristic types of activity at the end of the rising phase: I_v, a peak of activity at the end of the rising phase which was greater in voltage than that of the lowering phase peak; and II_v, a plateau of activity at the end of the rising phase which was lower in voltage than that of the lowering phase peak (Fig. 4). Ballet and modern dancers differed significantly in activity at the end of the rising phase in these two muscles. In the ballet dancers vastus lateralis and medialis EMG activity included a peak at the end of the rising phase greater than the lowering phase peak (I_v) in almost all grand-pliés; in contrast, the majority of EMG tracings in modern dancers had activity at the end of the rising phase less than the lowering phase peak (II_v) (difference between ballet and modern dancers: vastus lateralis, $df = 1$, $\chi^2 = 32.33$, $P < 0.001$; vastus medialis, $df = 1$, $\chi^2 = 37.93$, $P < 0.001$) (Table 3), similar to previous observations in demi-plié (26).

For both vastus lateralis and medialis (all grand-pliés), the average ratio between the lowering phase peak and midcycle valley RMS voltage, as well as between the rising phase peak and midcycle valley RMS voltage, was significantly greater for ballet than modern dancers (Table 4). For all 60 grand-pliés (all dancers), the rising phase RMS volt-

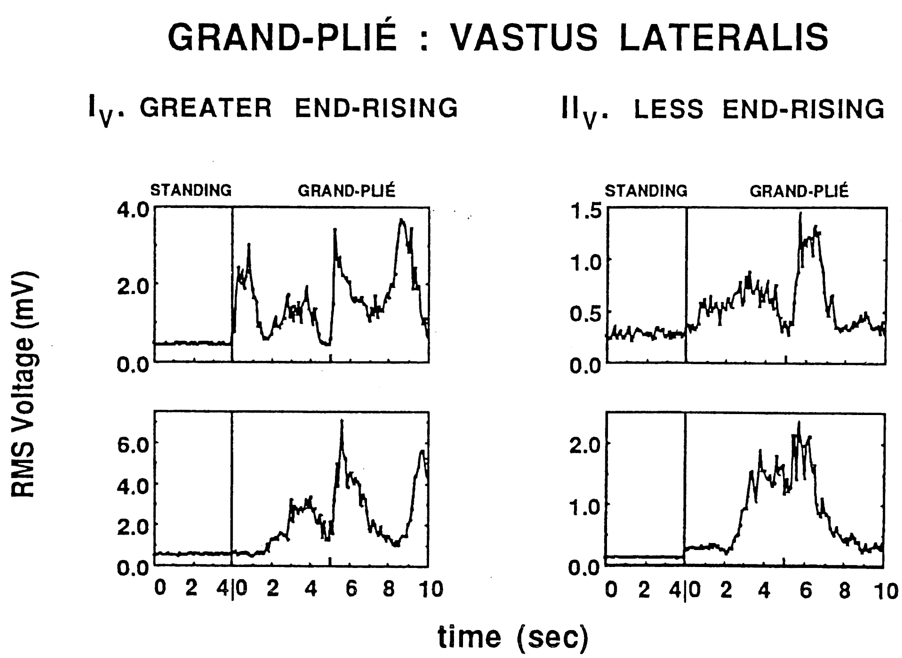

Figure 4—Surface electromyography of vastus lateralis during grand-plié. Representative plots of each of the four observed patterns of RMS voltage against time during grand-plié are demonstrated adjacent to one of the standing posture EMG plots for the same dancer. All grand-pliés had a broad lowering phase peak of activity, a decrease in activity (valley) at midcycle, followed by an asymmetric broad rising phase peak with maximum activity during the early part of the rising phase; the rising phase peak was of greater maximum voltage than the lowering in all 60 grand-pliés. Type I_v (left column) included plots with a peak of activity at the end of the rising phase which was greater in voltage than the lowering phase peak; type II_v (right column) included plots with a plateau of rising phase activity lower in voltage than the lowering phase peak. Similar plots were observed for vastus medialis.

TABLE 3. EMG activity in vastus lateralis and medialis during grand-plié in ballet and modern dancers. Number (percent) of EMG tracings I_V and II_V in ballet and modern dancers.[a]

	I_V			II_V			
	Ballet	Modern	Total	Ballet	Modern	Total	χ^2, $P <$ [b]
Vastus lateralis	23 (92%)	5 (14%)	28 (47%)	2 (8%)	30 (86%)	32 (53%)	32.33, 0.001
Vastus medialis	21 (84%)	1 (3%)	22 (37%)	4 (16%)	34 (97%)	38 (63%)	37.93, 0.001

[a] $N = 60$ (total), 25 (ballet), 35 (modern); I_V, peak at the end of rising phase greater than lowering phase peak; II_V, rising phase activity less than lowering phase peak.
[b] Comparison between ballet and modern dancers, $df = 1$; NS: $\chi^2 < 3.84$, $P > 0.05$.

age peak maximum was greater than lowering phase RMS voltage peak; the ratio between the rising and lowering phase peak maxima was significantly greater for ballet than modern dancers for vastus lateralis, but not medialis (Table 4).

In approximately one-third of all vastus lateralis and medialis EMG tracings, there was an additional peak of activity during the first second of EMG recording, just before beginning the grand-plié (Fig. 4). The frequency of this activity was significantly greater for ballet than for modern dancers for both vastus lateralis and medialis (Table 5).

Adductors. All grand-pliés had characteristic adductor EMG activity, consisting of lowering phase activity, a midcycle valley, and rising phase activity with a peak maximum early in the rising phase (Fig. 5). There were two distinct patterns observed: I_{AD}, consisting of a broad lowering phase peak, midcycle valley activity equal to or slightly above resting baseline voltage, and a tall peak early in the rising phase, in 19 (38%) grand-pliés; and II_{AD}, a broad peak of activity from heel-off (lowering phase) to heel-on (rising phase), including a lowering phase maximum before midcycle, midcycle valley with voltage less than the lowering phase peak maximum, and an asymmetric broad rising phase peak with maximum activity early in the rising phase, tapering to baseline at heel-on, in 31 (62%) grand-pliés (Table 6 and Fig. 5). Ballet and modern dancers differed significantly in adductor EMG tracing patterns; the majority of grand-pliés in ballet dancers were type I_{AD}, and in modern dancers the majority were type II_{AD} (Table 6).

Lateral and medial gastrocnemius, gluteus maximus, and hamstrings. In grand-plié, the EMG tracings for the lateral and medial gastrocnemius, gluteus maximus, and hamstrings were varied. There was no unique way that these muscles were used to accomplish the movement for all dancers.

TABLE 4. EMG activity in vastus lateralis and medialis during grand-plié in ballet and modern dancers. Ratios comparing RMS voltage at lowering phase peak, midcycle valley, and rising phase peak (mean ± SD).

	Ballet	Modern	t, $P <$ [a]
Lowering peak/midcycle valley			
Vastus lateralis	3 ± 2	1.5 ± 0.5	4.11, 0.001
Vastus medialis	6 ± 5	1.7 ± 0.6	4.41, 0.001
Rising peak/midcycle valley			
Vastus lateralis	6 ± 3	3 ± 1	4.52, 0.001
Vastus medialis	12 ± 9	3 ± 2	4.65, 0.001
Rising peak/lowering peak			
Vastus lateralis	2.3 ± 0.4	1.9 ± 0.5	3.18, 0.005
Vastus medialis	2.2 ± 0.5	2.0 ± 0.4	1.88, NS

[a] Comparison between ballet and modern dancers, $df = 58$; NS: $t < 2.00$, $P > 0.05$.

For lateral gastrocnemius, three EMG waveform patterns were observed (Fig. 6): I_{LG}, midcycle peak voltage greater than that of lowering and rising phases from heel-off to heel-on; II_{LG}, greatest activity during the lowering and/or rising phase, with or without midcycle activity; and III_{LG}, activity from heel-off (lowering phase) to heel-on (rising phase) with midcycle valley. There was no significant difference between ballet and modern dancers in lateral gastrocnemius EMG waveform distribution (Table 7).

For medial gastrocnemius, six EMG waveform patterns were observed (Fig. 7): I_{MG}, maximum activity at midcycle; II_{MG}, lowering phase peak after heel-off and peak at end of the rising phase; III_{MG}, activity from heel-off (lowering phase) through heel-on (rising phase), with midcycle valley; IV_{MG}, peak at end of rising phase; V_{MG}, early lowering phase peak (from start to heel-off), and activity at end of the rising phase; VI_{MG}, short spike of activity immediately after midcycle (early rising phase). Ballet and modern dancers differed significantly in medial gastrocnemius EMG waveform distribution, primarily because all V_{MG} tracings were in modern, and all VI_{MG} were in ballet dancers (Table 7).

Gluteus maximus EMG tracings were of six waveform patterns (Fig. 7): I_{GMax}, broad peak with maximum just before midcycle; II_{GMax}, midcycle peak; III_{GMax}, early lowering phase peak and rising phase activity; IV_{GMax}, early lowering phase peak, rising phase activity, and midcycle peak; V_{GMax}, lowering phase peak with maximum after heel-off, and rising phase peak; and VI_{GMax}, activity from heel-off (lowering phase) through heel-on (rising phase), with brief midcycle valley. Ballet and modern dancers differed significantly in gluteus maximus EMG waveform distribution (Table 7).

Hamstrings EMG tracings were of three distinct patterns (Fig. 6): I_{HS}, peak from late lowering through early rising phases, with brief midcycle valley; II_{HS}, rising phase activity; and III_{HS}, lowering activity followed by midcycle valley and early rising phase peak, analogous to the quadriceps and adductors (Figs. 4 and 5). Ballet and modern dancers differed significantly in hamstrings EMG waveform distribution because most I_{HS} tracings were in ballet, and most III_{HS} tracings were in modern dancers (Table 7).

Despite the variation observed for these four muscles, less variation of EMG plot patterns was observed between the five grand-plié repetitions of a given subject (Table 8) than had been observed previously for demi-plié (26). The majority of dancers demonstrated a unique pattern of muscle activity that was reproduced with one plot pattern in all five

TABLE 5. EMG activity in vastus lateralis and medialis during grand-plié in ballet and modern dancers. Number (percent) of grand-pliés with anticipatory EMG activity (0–1 s).

	Ballet	Modern	Total	χ^2, $P <$ [a]
Vastus lateralis	16 (64%)	6 (17%)	22 (37%)	11.84, 0.001
Vastus medialis	11 (44%)	5 (14%)	16 (27%)	5.15, 0.025

[a] Comparison between ballet and modern dancers, $df = 1$; NS (not significant): $\chi^2 < 3.84$, $P > 0.05$.

repetitions of grand-plié in seven of the eight muscles tested; a minority had from two to four different plot patterns in five grand-plié repetitions (Table 8).

Electromyographic (EMG) activity in different component periods of grand-plié. The EMG tracings were graded for the presence or absence of activity in each component period of grand-plié, and the percentage of grand-plié repetitions with activity in each period was determined (Tables 9 and 10). For all dancers combined, EMG activity was present from heel-off to heel-on in most of the muscles for the majority of grand-pliés (Table 9). A few significant differences were noted between ballet and modern dancers in seven of the eight muscles tested (Table 10), with medial gastrocnemius being the only muscle having no differences between ballet and modern dancers in any component period of grand-plié (Table 10).

For the lowering phase of grand-plié, the overall presence of EMG activity for all muscles (all dancers) was significantly less from start to heel-off (1–2 s) than from heel-off to midcycle (2–5 s) ($df = 7$, $\chi^2 = 40.68$, $P < 0.001$), primarily because of greater frequency of activity in hamstrings and adductors from heel-off to midcycle (Table 9).

For the rising phase of grand-plié, the overall presence of EMG activity for all muscles (all dancers) was significantly greater from midcycle to heel-on (5–8 s) than from heel-on to end (8–9 s) ($df = 7$, $\chi^2 = 24.33$, $P < 0.001$) because of lower frequency of activity from heel-on to end in all muscles tested except quadriceps and gluteus maximus (Table 9).

The validity of using the five repetitions from each subject to form the total number of measurements (N) for grand-plié was tested as previously described (7,26). For each muscle the phases of grand-plié repetitions graded as having baseline or increased EMG activity were assigned a numeric value of 0 or 1, respectively. Then for each muscle, ANOVA was performed using these values for each phase of grand-plié, and variance within and between subjects was compared using F test. In only one case, gluteus maximus at end of the rising phase (8–9 s), was the variance within slightly greater than that between subjects, but this was not statistically significant (within subjects, $df = 44$, variance = 0.034; between subjects, $df = 11$, variance = 0.030; $F = 1.13$, $P > 0.05$). In all other cases, the variance between was equal to or greater than that within subjects. Therefore, because the variance within did not exceed that between subjects in any case, the use of the five repetitions from the 12 dancers to form the total N of 60 is justified.

Comparison between grand-plié, demi-plié, and standing posture. EMG activity in grand-plié was compared with that in demi-plié and standing posture for tibialis anterior, vastus lateralis, and vastus medialis, the muscles with little variation in EMG tracings for both these movements.

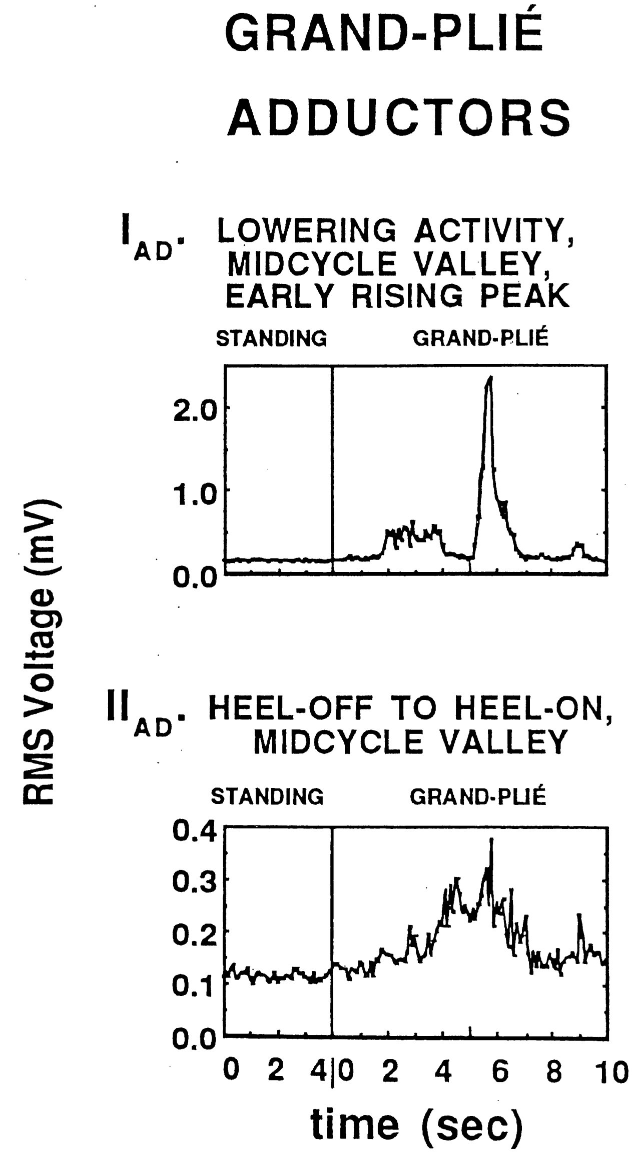

Figure 5—Surface electromyography of adductors during grand-plié. Representative plots of RMS voltage against time during grand-plié are demonstrated adjacent to one of the standing posture EMG plots for the same dancer. All grand-pliés had lowering phase activity, a midcycle valley, and rising phase activity with a peak maximum early in the rising phase. Type I_{AD} plots included a broad lowering phase peak, midcycle valley activity equal to or slightly above resting baseline voltage, and a tall peak early in the rising phase; type II_{AD} plots consisted of a broad peak of activity from heel-off (lowering phase) to heel-on (rising phase), including a lowering phase maximum before midcycle, midcycle valley with voltage less than the lowering phase peak maximum, and an asymmetric broad rising phase peak with maximum activity early in the rising phase, tapering to baseline at heel-on.

TABLE 6. EMG activity in adductors during grand-plié: number (percent) of EMG tracing types.[a]

	Ballet	Modern	Total
I_{AD}	12 (60%)	7 (23%)	19 (38%)
II_{AD}	8 (40%)	23 (77%)	31 (62%)
χ^2, $P <$ [b]		5.38, 0.025	

[a] Adductors: $N = 50$ (all dancers); 20 (ballet); 30 (modern).
[b] Comparison between ballet and modern dancers, $df = 1$; NS (not significant): $\chi^2 < 3.84$, $P > 0.05$.

For tibialis anterior at midcycle, peak EMG activity was less for grand-plié than demi-plié; the RMS voltage ratio of midcycle grand-plié to midcycle demi-plié was 0.7 ± 0.4 (all dancers). The ratio of tibialis anterior RMS voltage at midcycle demi-plié to standing posture was 21 ± 12 (all dancers), and midcycle grand-plié to standing posture was 13 ± 6 (all dancers). There were no significant differences between ballet and modern dancers in the ratios of tibialis anterior RMS voltage comparing midcycle grand-plié, midcycle demi-plié, and standing posture. During the rising phase, tibialis anterior activity in demi-plié was absent for all repetitions (26); in contrast, tibialis anterior activity in grand-plié was present in all repetitions from midcycle to heel-on (5–8 s), and in 42% of repetitions from heel-on to end (8–9 s) (Table 9).

For vastus lateralis and medialis, there were no significant differences between ballet and modern dancers in EMG activity at midcycle demi-plié (normalized to standing posture RMS voltage) (Table 11). However, ballet dancers had significantly less EMG activity than modern dancers at midcycle grand-plié (normalized to either midcycle demi-plié or standing posture RMS voltage) (Table 11). Ballet dancers had less (midcycle grand-plié to midcycle demi-plié RMS voltage ratio < 1), and moderns greater (ratio > 1) EMG activity at midcycle grand-plié than midcycle demi-plié (Table 11).

The visual similarity of the beginning and end of grand-plié (before heel-off and after heel-on) with that of demi-plié raised the question as to whether muscle activity is the same during the visually analogous components of the two different movements. Therefore, the number of repetitions in all dancers having EMG activity for all eight muscles tested, during the first and last second of grand-plié (Table 9) was compared with that of the lowering and rising phases of demi-plié (Table 6 in (26)), respectively. There was no difference in overall muscle activity between grand-plié from start to heel-off (1–2 s) and demi-plié lowering phase ($df = 7$, $\chi^2 = 13.04$, $0.05 < P < 0.10$). However, a significant difference in muscle activity between grand-plié from heel-on to end (8–9 s) and demi-plié rising phase, was observed ($df = 7$, $\chi^2 = 38.92$, $P < 0.001$), primarily as a result of tibialis anterior activity present in many grand-plié, but absent from all demi-plié, repetitions.

DISCUSSION

The current study is the first in which muscle activity in first position grand-plié has been analyzed using electromyography. Grand-plié was usually initiated with little or no lower extremity EMG activity. Lowering of the torso occurred as knee flexion and thigh abduction were controlled by eccentric contraction of the quadriceps and adductors, respectively, which peaked and then decreased to a valley at midcycle (Figs. 4 and 5). Stability of the hips and knees at midcycle was established in the majority of grand-pliés with contraction of the hamstrings (Fig. 6, Table 9), with minimal or low levels of activity in the quadriceps and adductors (Figs. 4 and 5); the gluteus maximus was not a prime stabilizer at midcycle, being active in only approximately one-half of the repetitions (Table 9). Rising of the torso was effected by concentric contraction of the quadriceps and adductors, with a large peak of activity early in the rising phase (Figs. 4 and 5); the gluteus maximus and hamstrings were also active early in the rising phase of most repetitions (Table 9). Stability of the dorsiflexed ankle from heel-off (lowering phase), through midcycle, to heel-on (rising phase) was associated with near isometric contraction of the tibialis anterior (Figs. 2 and 3).

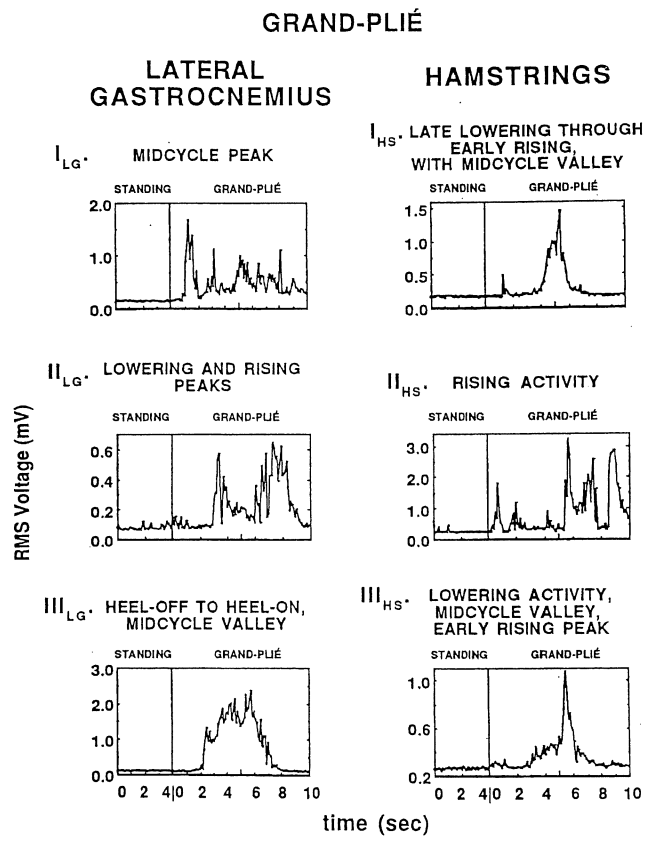

Figure 6—Surface electromyography of lateral gastrocnemius and hamstrings during grand-plié. Representative plots of RMS voltage against time during grand-plié are demonstrated adjacent to one of the standing posture EMG plots for the same dancer. For lateral gastrocnemius, the three patterns observed included: I_{LG}, midcycle peak voltage greater than that of lowering and rising phases from heel-off to heel-on; II_{LG}, greatest activity during the lowering and/or rising phase, with or without midcycle activity; and III_{LG}, activity from heel-off (lowering phase) to heel-on (rising phase) with midcycle valley. Hamstrings EMG tracings were of three patterns: I_{HS}, peak from the late lowering through the early rising phases, with brief midcycle valley; II_{HS}, rising phase activity; and III_{HS}, lowering activity followed by midcycle valley and the early rising phase peak.

TABLE 7. EMG activity in lateral gastrocnemius, medial gastrocnemius, gluteus maximus, and hamstrings during grand-plié: number (percent) of EMG tracing types.[a]

	Ballet	Modern	Total
Lateral gastrocnemius			
I_{LG}	2 (8%)	7 (20%)	9 (15%)
II_{LG}	20 (80%)	22 (63%)	42 (70%)
III_{LG}	3 (12%)	6 (17%)	9 (15%)
χ^2, $P <$ [b]		NS	
Medial gastrocnemius			
I_{MG}	0 (0%)	3 (9%)	3 (5%)
II_{MG}	5 (20%)	6 (17%)	11 (18.3%)
III_{MG}	5 (20%)	7 (20%)	12 (20%)
IV_{MG}	10 (40%)	8 (23%)	18 (30%)
V_{MG}	0 (0%)	11 (31%)	11 (18.3%)
VI_{MG}	5 (20%)	0 (0%)	5 (8.3%)
χ^2, $P <$ [c]		18.49, 0.005	
Gluteus maximus			
I_{GMax}	7 (28%)	1 (3%)	8 (13%)
II_{GMax}	0 (0%)	5 (14%)	5 (8%)
III_{GMax}	8 (32%)	0 (0%)	8 (13%)
IV_{GMax}	2 (8%)	2 (6%)	4 (7%)
V_{GMax}	7 (28%)	21 (60%)	28 (47%)
VI_{GMax}	1 (4%)	6 (17%)	7 (12%)
χ^2, $P <$ [c]		27.16, 0.001	
Hamstrings			
I_{HS}	16 (64%)	4 (11.5%)	20 (33.3%)
II_{HS}	8 (32%)	6 (17%)	14 (23.3%)
III_{HS}	1 (4%)	25 (71.5%)	26 (43.3%)
χ^2, $P <$ [b]		28.77, 0.001	

[a] $N = 60$ (total), 25 (ballet), 35 (modern).
[b] Comparison between ballet and modern dancers, $df = 2$; NS (not significant): $\chi^2 < 5.99$, $P > 0.05$.
[c] Comparison between ballet and modern dancers, $df = 5$; NS (not significant): $\chi^2 < 11.07$, $P > 0.05$.

The data also provide the first direct comparison between EMG activity in grand-plié and demi-plié. In contrast with the apparent consistency of muscle activity between subjects in normal walking (1), lower extremity muscle activity in grand-plié, as in demi-plié (26), was shown to comprise three major categories: (a) characteristic activity required for the execution of the movement; (b) varied activity specific to dancers of different dance idioms; and (c) varied activity between different repetitions and subjects, which may depend on factors such as balance, personal habit, and individual training background.

The unique EMG features of grand-plié differed from those of demi-plié, distinguishing the two movements. The torso lowering in demi-plié was effected primarily by a quadriceps-controlled knee bend (26), whereas in grand-plié, the adductors, quadriceps, hamstrings, and tibialis anterior were all of importance in control and stability of the lower extremities. Thus, grand-plié is not simply a "deep demi-plié," and may be of importance in training muscles that are not used in demi-plié. In grand-plié, the smaller area of plantar foot support from heel-off to heel-on necessitates greater active control of balance, and the lower torso position and greater knee flexion at midcycle results in the demand for more vigorous muscle activity during the early rising phase. The decreased variation of EMG activity observed in grand-plié (Table 8) compared with demi-plié (26) is consistent with previous observations in nondancers that increased exercise intensity tends to reduce variation and increase stereotypic motor patterns (12).

It is common practice for dancers to refer to the initial and terminal parts of grand-plié as the "demi" components of the movement. However, the current data demonstrate that the grand-plié is a fundamentally different movement than demi-plié, not only in how muscles are used from heel-off to heel-on, but also in components of grand-plié that visually resemble demi-plié. Anticipatory quadriceps activity was more often present in ballet than modern dancers before grand-plié, but not demi-plié (26). Furthermore, the two movements differed significantly in muscle activity between the rising phase of demi-plié and the final component of

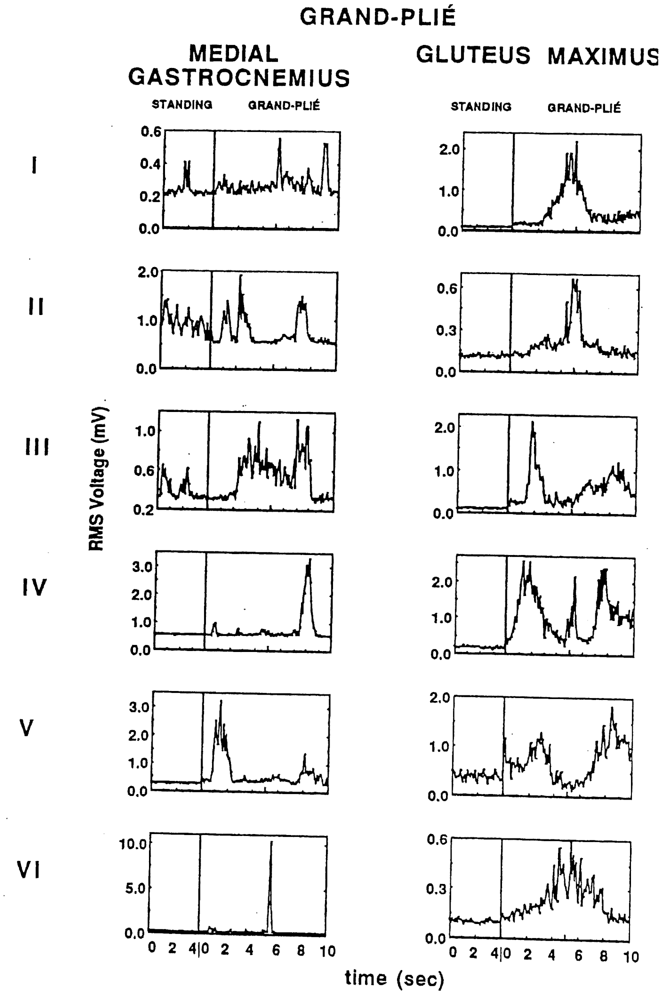

Figure 7—Surface electromyography of medial gastrocnemius and gluteus maximus during grand-plié. Representative plots of RMS voltage against time during grand-plié are demonstrated adjacent to one of the standing posture EMG plots for the same dancer. For medial gastrocnemius, the six patterns observed had activity as follows: I_{MG}, maximum activity at midcycle; II_{MG}, lowering phase peak after heel-off, and peak at end of the rising phase; III_{MG}, activity from heel-off (lowering phase) through heel-on (rising phase), with midcycle valley; IV_{MG}, peak at end of the rising phase; V_{MG}, early lowering phase peak (from start to heel-off), and activity at end of the rising phase; VI_{MG}, short spike of activity immediately after midcycle (early rising phase). Gluteus maximus EMG tracings were of six patterns: I_{GMax}, broad peak with maximum just before midcycle; II_{GMax}, midcycle peak; III_{GMax}, early lowering phase peak and rising phase activity; IV_{GMax}, early lowering phase peak, rising phase activity, and midcycle peak; V_{GMax}, lowering phase peak with maximum after heel-off, and the rising phase peak; and VI_{GMax}, activity from heel-off (lowering phase) through heel-on (rising phase), with brief midcycle valley.

TABLE 8. Variation in muscle activity in performing five grand-plié repetitions.

Muscle[a]	Total No. of Different EMG Plot Patterns (All Grand-Pliés)[c]	Number (percent) of Dancers Demonstrating 1, 2, 3, or 4 Different Patterns of EMG Plots in Five Grand-Plié Repetitions			
		One Pattern	Two Patterns	Three Patterns	Four Patterns
Lateral gastrocnemius	3	9 (75%)	2 (17%)	1 (8%)	—
Medial gastrocnemius	6	9 (75%)	1 (8%)	0 (0%)	2 (17%)
Tibialis anterior	3	8 (67%)	2 (17%)	2 (17%)	—
Vastus lateralis	4	7 (58%)	4 (33%)	1 (8%)	0 (0%)
Vastus medialis	4	4 (33%)	8 (67%)	0 (0%)	0 (0%)
Gluteus maximus	6	8 (67%)	1 (8%)	3 (25%)	0 (0%)
Hamstrings	3	7 (58%)	4 (33%)	1 (8%)	—
Adductors[b]	2	8 (80%)	2 (20%)	—	—

[a] All muscles except adductors: $N = 12$ dancers (total).
[b] Adductors only: $N = 10$ dancers (total); data not collected from one ballet and one modern dancer because of a shortage of coaxial cables.
[c] All dancers combined; 60 grand-pliés for all muscles (except adductors: 50 grand-pliés, because of cable shortage).

grand-plié (from heel-on to end), primarily because of tibialis anterior activity in this part of grand-plié (Fig. 3 and Table 9) not present in demi-plié (26). Therefore, a dancer's jargon or mental image may differ from reality with respect to muscle function. Furthermore, discussions of plié do not always distinguish between grand-plié or demi-plié (9,11,14), and the demonstrated differences underscore the importance of specifying which plié is being considered in discussions of dance movement.

The data for grand-plié and demi-plié at midcycle are consistent with previous observations of EMG activity of static postures in nondancers (19). In a posture analogous to midcycle of demi-plié, untrained nondancers had increased activity in both quadriceps and tibialis anterior; in contrast, in a squat position analogous to midcycle of grand-plié, activity in quadriceps and tibialis anterior was decreased, characteristic of the posture and not primarily a result of training (19). Some variation in EMG activity was noted in nondancers, attributed to individual differences in posture (19). However, quadriceps activity at midcycle of grand-plié was significantly less for ballet than modern dancers (Table 11), suggesting that the magnitude of this valley may be modulated by training or differences in turnout between the two groups. The midcycle valley in quadriceps (or adductor) activity may have been overlooked in a previous study of second position grand-plié because of visual difficulties inherent in assessing raw EMG data (4,5), which underscores the importance of analyzing the EMG tracings using integrated functions, such as RMS voltage, in EMG movement studies (1).

Patellofemoral joint reaction force is determined by both quadriceps force, which is proportional to the EMG signal, and angle of knee flexion (22). The decrease in quadriceps muscle force at midcycle of grand-plié, evidenced by the valley of EMG activity in vastus lateralis and medialis, may partially counterbalance the increased patellofemoral joint reaction force resulting from the larger angle of knee flexion (22). Therefore, patellofemoral joint reaction force in grand-plié may be lower than that predicted by models that are based on joint angle considerations alone (17), and it is inappropriate for dancers to exclude grand-plié from their training programs without considering both muscle activity as well as knee joint angle.

The observation of greater quadriceps activity at midcycle in modern than in ballet dancers, despite similar angle of knee flexion (Fig. 2 and Table 1), is evidence that modern dancers may have greater patellofemoral joint reaction force at midcycle (22) and, therefore, may be at greater risk for patellofemoral problems as a result of grand-plié than ballet dancers. This may explain in part the reduced emphasis of grand-plié in modern dance training compared with that in ballet training, and the greater reluctance of modern dance teachers to include grand-plié in class (17). The difference in quadriceps activity between ballet and modern dancers observed at midcycle, despite similar degrees of knee flexion and normalized height, is evidence that greater activity of these muscles is not required for stability of the lower extremities at midcycle, but that the modern dancers were actively contracting these muscles because of habit or training. In ballet class grand-plié is performed as the dancer rests her hand on the barre, which may facilitate the exercise, whereas no barre is used in modern dance training.

Training differences may also partially explain differences observed in quadriceps activity between ballet and

TABLE 9. EMG activity in lowering phase, midcycle, and rising phase of grand-plié. Number (percent) of grand-plié repetitions with activity above baseline for all (total) dancers.

Muscle[a]	Early Lowering (Start to heel-off) (1–2 s)	Late Lowering (Heel-off to midcycle) (2–5 s)	Midcycle (5 s)	Early Rising (Midcycle to heel-on) (5–8 s)	Late Rising (Heel-on to end) (8–9 s)
Lateral gastrocnemius	31 (52%)	58 (97%)	49 (82%)	60 (100%)	24 (40%)
Medial gastrocnemius	31 (52%)	30 (50%)	21 (35%)	58 (97%)	39 (65%)
Tibialis anterior	30 (50%)	60 (100%)	60 (100%)	60 (100%)	25 (42%)
Vastus lateralis	48 (80%)	60 (100%)	50 (83%)	60 (100%)	60 (100%)
Vastus medialis	47 (78%)	60 (100%)	51 (85%)	60 (100%)	57 (95%)
Gluteus maximus	43 (72%)	59 (98%)	32 (53%)	60 (100%)	58 (97%)
Hamstrings	9 (15%)	47 (78%)	51 (85%)	50 (83%)	24 (40%)
Adductors[b]	5 (10%)	50 (100%)	43 (86%)	50 (100%)	25 (50%)

[a] All muscles except adductors: $N = 25$ (ballet), 35 (modern), 60 (total).
[b] Adductors only: $N = 20$ (ballet), 30 (modern), 50 (total); data not collected from one ballet and one modern dancer because of shortage of coaxial cables.

TABLE 10. EMG activity in lowering phase, midcycle, and rising phase of grand-plié. Number (percent) of grand-plié repetitions with activity above baseline for muscles in which differences were observed between ballet and modern dancers.

Phase	Muscle[a]	Ballet	Modern	Total	χ^2, $P <$ [c]
Early lowering (1–2 s)	Lateral gastrocnemius	19 (76%)	12 (34%)	31 (52%)	8.56, 0.005
	Tibialis anterior	17 (68%)	13 (37%)	30 (50%)	4.39, 0.05
	Gluteus maximus	23 (92%)	20 (57%)	43 (72%)	7.09, 0.01
Late lowering (2–5 s)	None	—	—	—	—
Midcycle (5 s)	Vastus lateralis	16 (64%)	34 (97%)	50 (83%)	9.27, 0.005
	Vastus medialis	17 (68%)	34 (97%)	51 (85%)	7.56, 0.01
	Adductors[b]	13 (65%)	30 (100%)	43 (86%)	9.48, 0.005
Early rising (5–8 s)	Hamstrings	15 (60%)	35 (100%)	50 (83%)	14.04, 0.001
Late rising (8–9 s)	Tibialis anterior	19 (76%)	6 (17%)	25 (42%)	18.43, 0.001

[a] All muscles except adductors: $N = 25$ (ballet), 35 (modern), 60 (total).
[b] Adductors only: $N = 20$ (ballet), 30 (modern), 50 (total); data not collected from one ballet and one modern dancer because of a shortage of coaxial cables.
[c] Comparison between ballet and modern dancers, $df = 1$ for all tests; NS (not significant): $\chi^2 < 3.84$, $P > 0.05$.

modern dancers at the beginning and end of grand-plié. Although the frequency of anticipatory quadriceps activity was similar for ballet and modern dancers in demi-plié (26), significantly greater frequency of anticipatory quadriceps activity was observed in ballet than modern dancers in grand-plié (Table 5). At the end of grand-plié, the difference between ballet and modern dancers in quadriceps activity was similar to that observed in demi-plié, in which ballet dancers maintained greater genu recurvatum than modern dancers by active contraction of the quadriceps (26), possibly to achieve the genu recurvatum which is a characteristic esthetic feature of the lower extremity alignment of the ballet dancer (the "classical ballet line") (13,20,24).

The current results support the idea that, in contrast with demi-plié (26), the adductors are prime movers and stabilizers of the thigh in grand-plié from heel-off to heel-on (Fig. 5 and Table 9). It has been noted that in positions of greater turnout, where lower extremity motion occurs almost in the coronal plane, the adductors are oriented in an anatomically appropriate or ideal direction to contribute to this movement (4,5). Furthermore, lowering from start to midcycle of grand-plié is associated with large increases in adductor muscle length (4,5). Therefore, the practical importance of the adductor EMG data for the instructor who excludes grand-plié from a training program, is that she should seek alternate exercises to train the adductors for both eccentric and concentric work.

In contrast, the absence of adductor activity from start to heel-off in 90%, and from heel-on to end in 50%, of grand-pliés is evidence that activation of this muscle group is not imperative during these periods, similar to previous findings in the lowering and rising phases of demi-plié (26). Thus, the classical image that the adductors are active throughout the rising phase (14) was not applicable to many grand-pliés in the present study, because adductor activity was absent in many grand-pliés not only from heel-on to end (Table 9) but also after the early rising phase peak activity had returned to baseline, well before heel-on (Fig. 5).

The previously proposed role of the adductors of maintaining turnout throughout rising phase (14), which is controversial (11), is not supported by the present data, evidenced by the absence of adductor activity during major portions of this phase. The significant differences in turnout (26) and in adductor tracing patterns (Table 6) between the ballet and modern dancer groups in this study suggest that the adductors may, in part, actively contribute to the maintenance of turnout during components of grand-plié (14). However, turnout was maintained in the absence of adductor activity during rising phase in grand-plié after the early rising phase peak had returned to baseline (Fig. 5), as had been demonstrated in the rising phase of demi-plié (26). The proposed role of the adductors on control of turnout grand-plié may vary with degree of hip flexion or extension (10) and is probably of secondary importance to the primary function in regulation of thigh abduction-adduction (4). This controversy could be further clarified by EMG study of the adductors and other hip external rotators in individual dancers performing grand-pliés with different degrees of turnout.

The current study does not resolve the controversy regarding the safety of grand-plié or the appropriate timing of the introduction of grand-plié in the ballet or modern dance class (6,11,17). However, the EMG data provide an improved understanding of the important features of grand-plié, for which substitute exercises may be required if the movement is excluded by the teacher (6). In addition to the

TABLE 11. Comparison of EMG activity in tibialis anterior and quadriceps during grand-plié, demi-plié, and standing posture.

RMS Voltage Ratio[a]	Vastus Lateralis			Vastus Medialis		
	Ballet	Modern	t, $P <$ [b]	Ballet	Modern	t, $P <$ [b]
DP mid/ST	2.7 ± 0.5	3 ± 2	NS	7 ± 3	5 ± 3	NS
GP mid/ST	1.5 ± 0.6	4 ± 3	4.19, 0.001	3 ± 2	7 ± 3	3.98, 0.001
GP mid/DP mid	0.6 ± 0.3	1.3 ± 0.6	4.71, 0.001	0.5 ± 0.4	1.5 ± 0.9	4.20, 0.001
GP low/ST	4 ± 1	6 ± 3	3.01, 0.005	12 ± 4	11 ± 5	NS
GP ris/ST	9 ± 2	11 ± 5	2.04, 0.05	25 ± 9	20 ± 9	2.28, 0.05

[a] Mean ± SD. GP low, maximum RMS voltage at grand-plié lowering phase peak; GP mid, minimum RMS voltage at grand-plié midcycle valley; GP ris, maximum RMS voltage at grand-plié rising phase peak; DP mid, maximum RMS voltage at demi-plié midcycle peak; ST, RMS voltage during baseline standing.
[b] $N = 25$ (ballet), 35 (modern), 60 (total); $df = 58$, NS (not significant): $t < 2.00$, $P > 0.05$.

improvement of fine balance, the grand-plié may be useful in increasing strength and motor control of the adductors, quadriceps, hamstrings, and tibialis anterior (Figs. 3–6; Tables 9 and 10). More subtle results of dance training, such as changes in spinal reflex excitability (18), might occur in response to a traditional exercise, such as grand-plié, that emphasizes high levels of control and balance, and exclusion of specific movements from training programs might yield undesired effects that may be difficult to measure by clinical observation alone. Furthermore, as an intensely vigorous exercise with less lower extremity muscle variation than demi-plié (Table 8) (26), grand-plié may help the dancer in the development of stereotypic, automatic, intuitive movement (12) which may facilitate advancement from the isolated components of the training class to the complex sequences of the choreographed performance.

The authors thank the dancers, including those from Boston Ballet and Concert Dance Company, for participation in the study. The assistance of Ruth Solomon, K. Ramesh Murthy, William Gardner, John Solomon, and Anne Pavlik is gratefully acknowledged, as well as photographic assistance from Sarah Whitaker.

The project was supported in part by grants from the Paul Trepman Memorial Fund, Children's Sports Medicine Foundation (Boston), NeuroMuscular Research Center (Boston University), and the New England Baptist Bone and Joint Institute.

Part of this work was presented at the fifth annual meeting of the International Association for Dance Medicine and Science, Tel Aviv, Israel, June 12–15, 1995.

Address for correspondence: E. Trepman, M.D., Boston Foot and Ankle Center, New England Baptist Hospital, 70 Parker Hill Avenue, Suite 508, Boston, MA 02120.

REFERENCES

1. Basmajian, J. V. and C. J. De Luca. *Muscles Alive: Their Functions Revealed by Electromyography,* 5th Ed. Baltimore: Williams & Wilkins, 1985, pp. 1–561.
2. Black, K. P., J. M. Schmitz, G. F. Harris, K. M. Clavette, and W. G. Raasch. An electromyographic and cinematographic analysis of the pointe movement in ballet (Abstract). *American Academy of Orthopaedic Surgeons, 62nd Annual Meeting, Orlando, FL,* 1995, p. 136.
3. Chatfield, S. J. Electromyographic response of dancers to isokinetic work and select dance movements. *Kinesiol. Med. Dance* 16:60–82, 1993–94.
4. Clippinger-Robertson, K. *Incidence and Etiology of Patellofemoral Complaints in Dancers.* (Thesis), Seattle, WA: University of Washington, 1984, pp. 1–110.
5. Clippinger-Robertson, K. S., R. S. Hutton, D. I. Miller, and T. R. Nichols. Mechanical and anatomical factors relating to the incidence and etiology of patellofemoral pain in dancers. In: *The Dancer as Athlete*, C. G. Shell (Ed.). Champaign, IL: Human Kinetics Publishers, 1986, pp. 53–72.
6. Clouser, J. The grand plié: some physiological and ethical considerations. *Impulse* 2:83–86, 1994.
7. Fisher, R. A. *Statistical Methods for Research Workers*. Darien, CT: Hafner Publishing Company, 1970.
8. Fitt, S. S. The use of observation techniques for the identification of neuromuscular excitation patterns. *Dance Res. Ann. (CORD)* 10:157–172, 1979.
9. Gantz, J. Evaluation of faulty dance technique patterns: a working model. *Kinesiol. Med. Dance* 12:1–11, 1989–90.
10. Green, D. L. and J. M. Morris. Role of adductor longus and adductor magnus in postural movements and in ambulation. *Am. J. Phys. Med.* 49:223–240, 1970.
11. Grieg, V. *Inside Ballet Technique*. Pennington, NJ: Princeton Book Co., 1994, pp. 1–126.
12. Hellebrandt, F. A. and J. C. Waterland. Expansion of motor patterning under exercise stress. *Am. J. Phys. Med.* 41:56–66, 1962.
13. Howse, A. J. G. Orthopaedists aid ballet. *Clin. Orthop.* 89:52–63, 1972.
14. Howse, J. and S. Hancock. *Dance Technique and Injury Prevention*. New York: Theatre Arts Books/Routledge, 1988, pp. 1–196.
15. Mackie, J. *Basic Ballet*. New York: Penguin Books, 1978, pp. 1–127.
16. Muybridge, E. *The Human Figure in Motion*. New York: Dover Publications, 1955.
17. Myers, M. Is the grand plié obsolete? *Dancemagazine* 56(June): 78–80, 1982.
18. Nielsen, J., C. Crone, and H. Hultborn. *H*-reflexes are smaller in dancers from The Royal Danish Ballet than in well-trained athletes. *Eur. J. Appl. Physiol.* 66:116–121, 1993.
19. Okada, M. An electromyographic estimation of the relative muscular load in different human postures. *J. Hum. Ergol.* 1:75–93, 1972.
20. Quirk, R. The dancer's knee. In: *Dance Medicine: A Comprehensive Guide*, A. J. Ryan and R. E. Stephens (Eds.). Chicago: Pluribus Press, 1987, pp. 177–219.
21. Ranney, D. Biomechanics of dance. In: *Science of Dance Training*, P. M. Clarkson and M. Skrinar (Ed.). Champaign, IL: Human Kinetics Books, 1988, pp. 125–144.
22. Reilly, D. T. and M. Martens. Experimental analysis of the quadriceps muscle force and patello-femoral joint reaction force for various activities. *Acta Orthop. Scand.* 43:126–137, 1972.
23. Ryman, R. S. and D. A. Ranney. A preliminary investigation of two variations of the *grand battement devant. Dance Res. J.* 11:2–11, 1979.
24. Stephens, R. E. The etiology of injuries in ballet. In: *Dance Medicine: A Comprehensive Guide*, A. J. Ryan and R. E. Stephens (Eds.). Chicago: Pluribus Press, 1987, pp. 16–50.
25. Trepman, E., R. E. Gellman, R. Solomon, K. R. Murthy, L. J. Micheli, and C. J. De Luca. Electromyographic analysis of dance motion: demi-plié. In: *The Eighth International Jerusalem Symposium on Sport Injuries*, G. Mann (Ed.). Jerusalem, Israel: Israel Society of Sports Medicine, 1992, pg. 37.
26. Trepman, E., R. E. Gellman, R. Solomon, K. R. Murthy, L. J. Micheli, and C. J. De Luca. Electromyographic analysis of standing posture and demi-plié in ballet and modern dancers. *Med. Sci. Sports Exerc.* 26:771–782, 1994.