Electromyographic analysis of standing posture and demi-plié in ballet and modern dancers

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ABSTRACT

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.* Vol. 26, No. 6, pp. 771–782, 1994. Surface electromyography was used to analyze lower extremity muscle activity during standing posture and demi-plié in first position with lower extremities turned out, in five ballet and seven modern female professional dancers. In standing posture, increased electromyographic (EMG) activity above baseline was detected most frequently at the medial gastrocnemius (54% standing repetitions) and tibialis anterior (29%) electrodes (all dancers); in ballet dancers, increased EMG activity during standing was significantly less frequent at the medial gastrocnemius, but more frequent at the tibialis anterior, than in modern dancers. In demi-plié, the tibialis anterior had a discrete peak of EMG activity at midcycle in all dancers (97% demi-pliés). All dancers also had midcycle EMG activity in both vastus lateralis and medialis (100% demi-pliés). At the end of rising phase of demi-plié, ballet dancers had greater EMG activity than at midcycle in vastus lateralis (100% demi-pliés) and medialis (92%); in modern dancers, end-rising phase voltage was lower than at midcycle for vastus lateralis (71% demi-pliés) and medialis (83%). Genu recurvatum $\geq$ 10 degrees was observed at the beginning and end of demi-plié in all ballet dancers, but not in modern dancers. There was marked variation of EMG activity during demi-plié in the lateral gastrocnemius, medial gastrocnemius, gluteus maximus, hamstrings, and adductors. The results support the hypothesis that ballet and modern dancers have different patterns of muscle use in standing posture and demi-plié, which in part may be a result of differences in genu recurvatum and turnout between the two groups.

ELECTROMYOGRAPHY, DANCE, MOTION ANALYSIS

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There is very little information available about the way dancers use their muscles to perform highly trained and aesthetically beautiful movements. Studies of dance activity have focused primarily on the etiology and treatment of specific injuries sustained by dancers (11,28). Biomechanical errors in technique that contribute to single-impact and overuse dance injuries have been described (10,26,33). However, studies of dance movement are limited (27) and have been based primarily on techniques such as motion picture analysis (9,17), angular momentum measurement (19), and mechanical modelling (18).

In nondancers, electromyography has enabled the reliable documentation and description of muscle activity in standing posture (1,14), gait (1,7,16,35), and sports activities such as archery, golf, tennis, and weightlifting (5,12,24). Only two electromyographic (EMG) movement studies in dancers have been previously reported (6,29). In an EMG analysis of the grand battement devant (forward kick) in four teenage ballet dancers, the observed muscle activity and movement patterns differed from traditional descriptive ballet models (29). In another study, electromyography was used to analyze quadriceps function in grand-plié, a deep knee bend in which the heels are raised off the floor as the knees are further flexed, in dancers with and without patellofemoral pain (6). EMG descriptions of other fundamental dance movements are not available. The practical problem is that current anatomic concepts of dance training and injury rehabilitation are based on qualitative images of specific muscle function in dance movement that have not been tested with quantitative techniques such as electromyography. An anatomic approach to dance training may lead to greater efficiency of movement and reduce injury risk (30), but there is little objective evidence to support or refute the anatomic accuracy of such models.

Classical ballet and modern dancers differ in training technique, movements used in choreography, and shoewear. In contrast with modern dance, ballet movements often involve greater degrees of lower extremity lateral rotation (turnout). Furthermore, female ballet, but not modern, dancers move and balance on the tips of the toes using a special toe shoe (*en pointe*), an activity that has been associated with injury to the flexor hallucis longus tendon in ballet dancers rarely observed in other athletes (8). These differences suggest the hypothesis that ballet and modern dancers have different patterns of muscle use in similar movements. Therefore, we performed a study of fundamental dance movements in ballet and modern dancers using electromyography to document lower extremity muscle activity, and to determine the effect of different training background on patterns of muscle use.

Demi-plié is the dance movement in which the upright torso is lowered with hip and knee flexion and ankle dorsiflexion, and then raised back to the starting position; the feet remain flat on the floor throughout the movement. The demi-plié is the most basic of dance movements, because it is the foundation of all dance training and also the pivot from which other movements, such as jumps, occur. The purpose of this report is to describe lower extremity muscle activity in turned out standing posture and demi-plié, as determined by EMG analysis, and to present data that support the hypothesis that ballet and modern dancers use muscles differently in standing posture and demi-plié.

MATERIALS AND METHODS

Subjects

Five ballet (Boston Ballet Company) and seven modern (Concert Dance Company and other local Boston companies) female professional dancers volunteered for the study. Written informed consent to participate in the study was given by each subject. Demographic characteristics and dance history of the two groups are summarized in Table 1. The ballet and modern dancers were of similar average height and weight. Furthermore, average amount of dance experience and current dance hours per week were similar for the two groups (Table 1). Although modern dancers were currently involved in some ballet activity, this was significantly less than for the ballet dancers (Table 1). All subjects were healthy and without active injury, except for one ballet dancer who had undergone arthrotomy of the right ankle and subtalar joint for excision of loose bodies and osteophytes 3 wk prior to the study.

TABLE 1. Characteristics and dance experience of study subjects.

	Ballet	Modern	Total	t, $P <$ *
No. subjects	5	7	12	—
Age (yr)	29 ± 8	35 ± 9	33 ± 9	NS
Height (in)	64.7 ± 0.7	63 ± 2	64 ± 2	NS
Weight (lbs)	111 ± 4	112 ± 5	112 ± 4	NS
Dance experience (yr)				
Age started dance (yr)	7 ± 2	10 ± 6	8 ± 5	NS
Age started *pointe* (yr)	11.8 ± 0.4	15 ± 4‡	13 ± 3	—
No. yr preprofessional	12 ± 3	12 ± 6	12 ± 5	NS
No. yr professional	11 ± 6	12 ± 12	12 ± 9	NS
Total no. yr dance	23 ± 7	24 ± 12	24 ± 10	NS
Current dance activity				
$h \cdot wk^{-1}$†	36 ± 4	30 ± 8	32 ± 7	NS
% Ballet activity	100 ± 0	11 ± 13	—	3.24, 0.01
% Modern dance activity	0 ± 0	87 ± 14	—	3.22, 0.01
% Other dance activity	0 ± 0	1 ± 4	—	NS

Values expressed as mean ± standard deviation.

* Comparison between ballet and modern groups: Student's t test, $df = 10$; NS (not significant): $t < 2.23$, $P > 0.05$.

† Excluding one semi-retired ballerina and one modern dancer whose current dance activity was each 12 $h \cdot wk^{-1}$.

‡ Only three of seven modern dancers reported experience *en pointe*.

Electromyographic (EMG) Arrangement

After the subjects warmed up for a period of 10 min, EMG parallel bar active surface electrodes (NeuroMuscular Research Center, Boston University, Boston, MA) were applied. Eight muscles were selected for study: lateral gastrocnemius, medial gastrocnemius, tibialis anterior, vastus lateralis, vastus medialis, gluteus maximus, hamstrings, and adductors. Muscles on the right side of the body only were tested for the symmetrical movements described in this report; limitations in the available hardware precluded simultaneous bilateral EMG recording. The skin over the center of the muscle was cleansed with alcohol and allowed to dry. The eight electrodes and a ground electrode were then fastened securely with a small piece of Steri-Drape™ (3M, St. Paul, MN) to the skin over the center of the widest part of the muscle bellies, except for the electrode for the hamstrings, which was placed at the center of the posterior thigh, halfway between medial and lateral hamstrings. Absence of visible motion between electrode and skin was confirmed after placement of the electrodes. Data from the adductor electrode were not collected from one ballet and one modern dancer because of a shortage of coaxial cables during this recording session.

Electrodes were connected to an EMG preamplifier (NeuroMuscular Research Center, Boston University, Boston, MA), which was placed in the lumbar pocket of a belt secured around the waist and connected via a cable to an EMG interface box (NeuroMuscular Research Center), from which the EMG signal was delivered to an analog/digital unit (Watscope, Northern Digital Inc., Waterloo, Ontario) and amplifier (Tektronix, Inc., Beaverton, OR). The dancer moved about to ensure that the arrangement did not interfere with comfortable dance movement. Appropriate electrode placement was confirmed with a maximal, resisted isometric contraction of each muscle tested. Raw EMG signals were amplified (20–400 Hz) and sampled at 1 kHz using data collection software (Watscope, Northern Digital Inc., Waterloo, Ontario).

Position of Subjects, Movements Performed, and Data Collection

All movements in the study were performed with the dancers in classical first position (anatomic position with lower extremities laterally rotated and heels together). Each dancer was instructed to select the maximum amount of lower extremity lateral rotation (turnout) that was comfortable; although this varied between subjects, it was judged more appropriate for the current study to analyze movement in a comfortable first position rather than to select an arbitrary amount of turnout that might have been uncomfortable to some of the dancers, possibly resulting in altered muscle activity. However, for each dancer the amount of turnout was identical for all repetitions of movements; variation in the amount of turnout between different repetitions was avoided by making an outline drawing of the feet on recording paper taped to the floor at the beginning of the session, and this served as a reference for placement of the feet for all repetitions. The turnout was quantitated from the drawing as the angle between lines drawn from the second toe to the middle of the heel. The subjects were barefoot for all movements in the study, except for two ballet dancers who wore socks.

Simultaneous EMG and videotape data were then collected while the subjects performed timed dance movements. The videotape camera was positioned to record either the anteroposterior (AP), right lateral, or 45 degree right-lateral oblique view of different repetitions. For standing posture, the dancers were asked to stand comfortably at rest in first position, and EMG activity was recorded during a 4-s period (three repetitions). The videotape view recorded for the first standing repetition was AP, second lateral, and third oblique.

To facilitate description and analysis of demi-plié, we defined the demi-plié cycle as consisting of two phases: (i) lowering phase, during which the torso is lowered; and (ii) rising phase, in which the torso rises to neutral (Fig. 1). The instant at which the torso is lowest, with the hips and knees at maximum flexion, was defined as midcycle. In practice, the duration of the lowering and rising phases may differ, such as when the dancer comes out of midcycle rapidly to jump; nevertheless, in much dance training at the barre, equal counts are used for lowering and rising phases. Therefore, for simplicity of analysis, in this study lowering and rising phases were of equal duration.

The dancers performed a 6-s demi-plié (five repetitions), timed to a count announced by an assistant using a stopwatch so that the lowering and rising phases were each 3 s. With the dancer in first position ready to start,

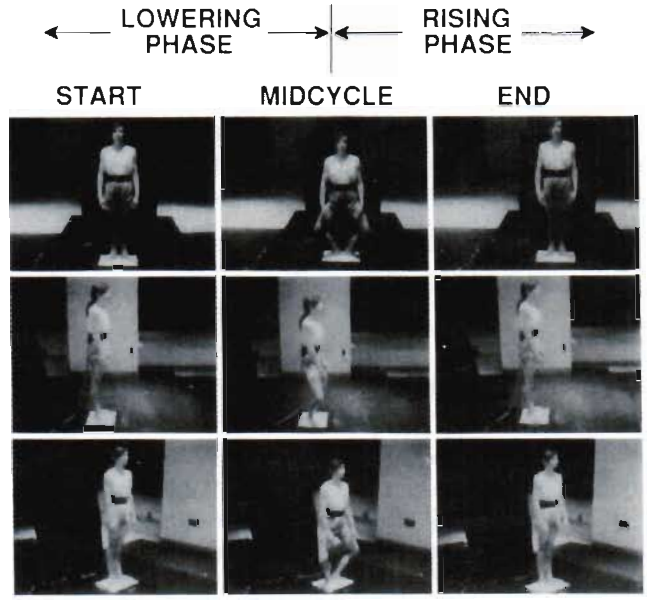

Figure 1—Photographs of ballet dancer performing demi-plié in classical first position (turned out), as seen from front (*top row*), side (*middle row*), and oblique (*bottom row*) views. The dancer is positioned upright just before the start of demi-plié (*left column*), proceeds through lowering phase to midcycle (*middle column*), and then through rising phase to completion of the movement at the end of rising phase (*right column*).

announcement at 1-s intervals was commenced 2 s before beginning the demi-plié movement so that she would be ready to start at the desired time. EMG activity was recorded beginning 1 s before onset of the demi-plié, and continued a full second after completion of the movement (total recording interval 8 s). The videotape view recorded for the first and fourth demi-plié repetitions was AP, second and fifth lateral, and third oblique. Upper extremity movements were not restricted or controlled; however, in both standing posture and demi-plié, all dancers held the upper extremities in classical first position port de bras (shoulders slightly forward flexed and internally rotated almost 90 degrees, elbows slightly flexed, and hands held comfortably open) (Fig. 1) except in one demi-plié repetition in one dancer.

Joint range of motion was measured by a single observer from the videotape by goniometry, using the videotape view most orthogonal to the plane of joint motion. The center of rotation of each joint and the longitudinal axes of the adjacent limb segments were visually estimated by viewing the complete movement repetition, and the measurements were then made from stopped images at different times during a replay of the videotape. Left ankle dorsiflexion and left knee flexion were measured from the videotape view 45 degrees oblique to the dancer, which was the view closest to true lateral of the knee and ankle in the turned out lower extremity; left hip abduction was measured from the AP view, and right hip flexion from the lateral view. Forward and backward sway (sagittal movement) of the torso was determined from the lateral view by measurement of the change in distance between a fixed landmark (wall panel) and a reference point on the torso at the start, midcycle, and end of demi-plié; the ratio between known standing height and height measured on the videotape at the start of demi-plié was used to convert measured sway on the videotape to actual sway.

Data Analysis

EMG data were processed using a program (WATS2A) written specifically for calculation of root-mean-square (RMS) voltage for 0.10-s intervals (1). RMS data were plotted against time for each of the eight muscles, and the plots were analyzed for EMG activity as described below. The same voltage ranges were used for plots of standing posture and demi-plié EMG activity for each muscle for purposes of comparison.

For standing posture repetitions, each RMS voltage plot was graded as having either (i) baseline voltage throughout the entire period of data collection, or (ii) activity increased above baseline. The criterion for grading a plot as having baseline activity was the absence of any increased activity above baseline throughout the entire period of the repetition; plots that had a single minimal peak of activity (<10% of the 4-s period of the repetition) or activity less than 125% of baseline RMS voltage were also included in the baseline category. When there was increased activity throughout a standing repetition, the reference baseline was determined from the other standing repetitions or from the electrically inactive periods of the demi-plié plots of the same dancer.

Demi-plié EMG plots were analyzed two different ways. First, plots were classified into patterns based on the different relative amounts of RMS voltage between the different phases, and plot patterns of similar major features were grouped together into categories (types) on the basis of whether RMS voltage was greatest at midcycle or during lowering and/or rising phases. The number of EMG plots in each category was determined for each muscle. Second, each plot was graded as to whether increased EMG activity above baseline was present or not in each phase.

Demographic data, height, joint angles, and sway data are reported as mean ± standard deviation 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 analysis of variance (ANOVA) with one repeated measure, with dancer group as the between factor and time the within factor. Level of significance for all analyses was defined by $P \leq 0.05$.

RESULTS

Qualitative Observations and Goniometric Analysis

In adopting a comfortable turned out first position, ballet dancers stood with significantly greater angle of turnout than modern dancers (ballet: mean 120 ± 10 degrees, range 106–129 degrees; modern: mean 91 ± 8 degrees, range 75–99 degrees; $df = 10$, $t = 2.80$, $P < 0.02$). During standing posture, both groups of dancers had genu recurvatum, but this was significantly greater in ballet (average −13 ± 4 degrees; range −6 to −16 degrees) than modern (average −5 ± 2 degrees; range −2 to −7 degrees) dancers ($df = 10$, $t = 2.81$, $P < 0.02$).

When given the cue to start demi-plié (at time = 1 s on graphs and EMG plots), the ballet dancers visually appeared to initiate the movement rapidly, whereas modern dancers seemed to ease into the start more slowly. Ballet dancers started and completed the demi-plié with neutral ankle position and genu recurvatum, whereas moderns had slight ankle dorsiflexion and neutral knee position. Two-way ANOVA with one repeated measure revealed statistically significant differences between ballet and modern dancer groups for knee flexion ($df = 1$; $F = 6.27$; $P = 0.03$) and ankle dorsiflexion ($df = 1$; $F = 5.01$; $P = 0.05$) against time (Fig. 2). All ballet dancers had genu recurvatum ≥ 10 degrees (range of knee flexion −10 to −28 degrees) at the start and completion of demi-plié, but all moderns had approximately neutral knee position (range −4 to 2 degrees). Student's *t*-test at each time point revealed significant differences ($P \leq 0.05$) between ballet and modern dancer groups for both knee flexion and ankle dorsiflexion at 0, 6, 7, and 8 s, and for knee flexion alone at 4 s; at the other time points, the differences were not significant. There was no significant difference (two-way ANOVA) between ballet and modern dancers in height ($df = 1$; $F = 3.15$; $P = 0.1$), hip abduction ($df = 1$; $F = 0.046$; $P = 0.8$), or hip flexion ($df = 1$; $F = 3.05$; $P = 0.1$) against time (Fig. 2).

When demi-plié was viewed from the side, the torso appeared to sway forward toward the end of lowering phase, and backward during the early part of rising phase (Fig. 1). Measurement of torso sway from the videotape confirmed that in almost all demi-pliés for which a lateral videotape view was made (20/21 = 95%; three repetitions excluded from this analysis because videotape views were oblique, not true lateral), torso sway was forward during lowering phase (average 1.9 ± 1.4 cm; range −1.1 cm to 4.7 cm) and backward during rising phase (average 1.6 ± 1.3 cm; range −1.7 to 4.7 cm).

Electromyographic (EMG) Analysis of Standing Posture

Lower extremity muscle EMG tracings during standing posture were graded as having either (i) baseline

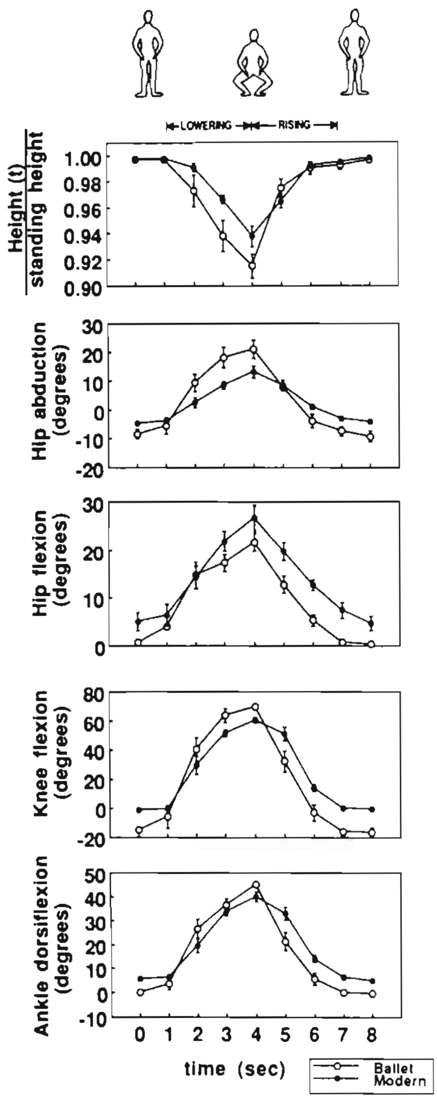

Figure 2—Height and lower extremity joint range of motion during demi-plié in ballet and modern dancers. EMG recording was started at time = 0 s and completed at 8 s. The dancers were instructed to start the demi-plié at time = 1 s, reach midcycle at 4 s, and complete the movement at 7 s; lowering and rising phases were each 3 s in duration. Height data were normalized to standing height. Plotted values are average ± standard error of the mean for the five ballet (*open circles*) and seven modern (*filled circles*) dancers; when not visible, error bars are smaller than the points.

voltage or (ii) EMG activity increased above baseline. Included in the latter category were tracings with either two or more short duration peaks (<1 s), broad peaks and plateaus of increased activity with or without superimposed peaks, or fluctuating peaks of increased activity spanning the entire period of measurement. Standing posture plots graded as having EMG activity increased above baseline were varied in amount of increased activity, ranging in duration from 13 to 100% of the 4-s period of measurement, and in magnitude from 125 to 1500% of baseline RMS voltage. When increased activity over short periods was observed, medial gastrocnemius and tibialis anterior activity was often inversely related, with short duration peaks of tibialis anterior activity corresponding to troughs of medial gastrocnemius activity, and vice versa; this relationship was also observed when short duration peaks or fluctuations in EMG activity were observed in the demi-plié.

When all dancers were considered together, EMG activity above baseline was most frequently detected by the medial gastrocnemius (54% of standing repetitions) and tibialis anterior (29%) electrodes (Table 2). In the repetitions graded as increased above baseline for these two electrodes, the percentage (average ± standard deviation) of the period of measurement consisting of increased activity was 60 ± 30% (range 23–100%) for the medial gastrocnemius, and 40 ± 10% (range 18–58%) for the tibialis anterior. For the other muscles tested, EMG activity was baseline in over 80–90% of standing repetitions (Table 2).

When ballet and modern dancers were analyzed separately, EMG activity detected by the medial gastrocnemius electrode was increased above baseline more than twice as often in modern than ballet dancers ($df = 1$, $\chi^2 = 4.60$, $P < 0.05$) (Table 2). Conversely, tibialis anterior activity was increased above baseline in the majority (64%) of standing repetitions in ballet dancers, but baseline in almost all modern repetitions (difference between ballet and modern groups significant, $df = 1$, $\chi^2 = 11.82$, $P < 0.001$) (Table 2).

Electromyographic (EMG) Analysis of Demi-Plié

In the 60 repetitions of demi-plié analyzed, there was little variation in EMG tracings from the tibialis anterior, vastus lateralis, and vastus medialis electrodes. In contrast, the other five muscles tested were characterized by marked heterogeneity of EMG activity.

Tibialis anterior. A peak of EMG activity at midcycle was observed in almost all demi-plié repetitions (58/60 = 97%) (Fig. 3); the only two in which a midcycle peak was not observed were in the ballet dancer who was recovering from ankle surgery 3 wk prior to the study. There were two characteristic types of tibialis anterior EMG

TABLE 2. Number (percent) of standing repetitions with increased EMG activity above baseline.

Muscle	All Dancers	Ballet	Modern	χ^2, $P <$ ‡
No. repetitions (*N*)*	35	14	21	
Lateral gastrocnemius	3 (9%)	0 (0%)	3 (14%)	NS
Medial gastrocnemius	19 (54%)	4 (29%)	15 (71%)	4.60, 0.05
Tibialis anterior	10 (29%)	9 (64%)	1 (5%)	11.82, 0.001
Vastus lateralis	3 (9%)	2 (14%)	1 (5%)	NS
Vastus medialis	3 (9%)	2 (14%)	1 (5%)	NS
Gluteus maximus	2 (6%)	2 (14%)	0 (0%)	NS
Hamstrings	6 (17%)	2 (14%)	4 (19%)	NS
Adductors†	2 (7%)	0 (0%)	2 (11%)	NS

* All muscles except adductors: 3 repetitions each for 12 dancers (except data for one repetition in a ballet dancer was lost).
† *N* = 30 (all dancers), 12 (ballet), 18 (modern); data not collected from one ballet and one modern dancer because of a shortage of coaxial cables.
‡ Comparison between ballet and modern dancers, $df = 1$ for all tests; NS (not significant): $\chi^2 < 3.84$, $P > 0.05$.

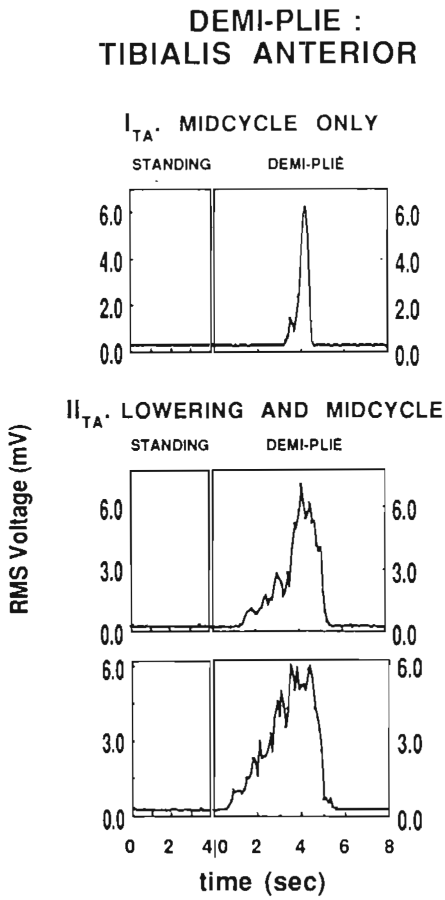

Figure 3—Surface electromyography of tibialis anterior during demi-plié. Representative plots of RMS voltage against time during demi-plié are demonstrated adjacent to one of the standing posture EMG plots for the same dancer. A peak of midcycle activity (I_{TA} and II_{TA}) was observed in almost all (58/60 = 97%) demi-pliés. Progressively increasing activity during lowering phase leading up to the midcycle peak (II_{TA}) was observed in 67% of demi-pliés.

activity: I_{TA}, midcycle peak alone (30% of demi-pliés); and II_{TA}, lowering phase activity of varied duration and voltage leading into the midcycle peak (67% demi-pliés) (Fig. 3). Lowering phase activity in type II_{TA} tracings was always of lower voltage than that of the midcycle peak (Fig. 3). The duration of lowering phase activity was quantitated by measuring the width of the EMG tracing from onset of increased lowering phase activity to termination of midcycle peak; 24/60 (40%) tibialis anterior tracings had increased activity less than or equal to 2.0 s, i.e., midcycle activity with minimal or no lowering phase activity, and 34/60 (56.7%) tracings had increased activity greater than 2.0 s, with 8/60 (13%) greater than or equal to 4.0 s. Mean duration of EMG activity was 2.4 ± 1.0 s.

In none of the 60 demi-plié repetitions was there any tibialis anterior activity in rising phase. There were no significant differences between ballet and modern dancers in tibialis anterior EMG behavior, as determined by either EMG tracing type classification (I_{TA} or II_{TA}) or duration of EMG activity.

Vastus lateralis and medialis. All demi-pliés had a broad midcycle peak of activity in both muscles, with increasing activity as lowering phase ended, followed by decreasing activity as rising phase began (Fig. 4); in five demi-pliés (one ballet dancer), EMG activity in vastus lateralis progressively increased throughout the entire demi-plié.

The EMG tracings for the vastus lateralis and medialis were classified on the basis of two characteristic types of rising phase activity: I_v, a peak of activity at the end of rising phase that was greater in voltage than that of the midcycle peak; and II_v, a plateau of rising phase activity lower in voltage than that of the midcycle peak (Fig. 4). For all dancers combined, vastus lateralis activity was I_v in 58% and II_v in 42% of the 60 demi-pliés, and vastus medialis activity was I_v in 48% and II_v in 52%. However, ballet and modern dancers differed significantly in rising phase activity in these two muscles. In the ballet dancers, vastus lateralis and medialis EMG activity included a peak at the end of rising phase greater than the midcycle peak (I_v) in almost all demi-pliés; in contrast, the majority of EMG tracings in modern dancers had rising phase activity less than the midcycle peak (II_v) (difference between ballet and modern dancers: vastus lateralis, $df = 1$, $\chi^2 = 27.64$, $P < 0.001$; vastus medialis, $df = 1$, $\chi^2 = 29.71$, $P < 0.001$) (Table 3).

In approximately one-half of vastus lateralis EMG tracings, and a majority of vastus medialis tracings, there was a peak of activity during the first second of EMG recording, just prior to beginning the demi-plié (Fig. 4). The frequency of this activity was the same in both groups

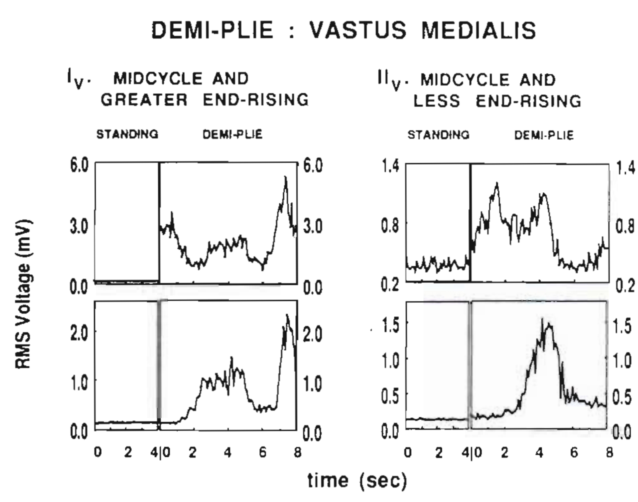

Figure 4—Surface electromyography of vastus medialis during demi-plié. Representative plots of each of the four observed patterns of RMS voltage against time during demi-plié are demonstrated adjacent to one of the standing posture EMG plots for the same dancer. All demi-pliés had a broad midcycle peak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

TABLE 3. EMG activity in vastus lateralis and medialis during demi-plié: number (percent) of EMG tracings I_v and II_v in ballet and modern dancers*.

Muscle	I_v All Dancers	I_v Ballet	I_v Modern	II_v All Dancers	II_v Ballet	II_v Modern	χ^2, $P <$ †
Vastus lateralis	35 (58%)	25 (100%)	10 (29%)	25 (42%)	0 (0%)	25 (71%)	27.64, 0.001
Vastus medialis	29 (48%)	23 (92%)	6 (17%)	31 (52%)	2 (8%)	29 (83%)	29.71, 0.001

* N = 60 (all dancers); 25 (ballet); 35 (modern); I_v: peak at the end of rising phase greater than the midcycle peak; II_v: rising phase activity less than the midcycle peak.
† Comparison between ballet and modern dancers. df = 1 for all tests; NS (not significant): $\chi^2 < 3.84$, $P > 0.05$.

of dancers for vastus lateralis (ballet, 14/25 = 56% of demi-pliés; modern, 20/35 = 57%); for vastus medialis, the frequency of the peak of activity before the start of demi-plié was also similar between ballet (20/25 = 80% of demi-pliés) and modern (23/35 = 66%) dancers (not significant, $df = 1$, $\chi^2 = 0.84$, $0.30 < P < 0.40$).

Lateral and medial gastrocnemius; gluteus maximus, hamstrings, and adductors. In demi-plié, the EMG tracings for the other five muscles tested—lateral and medial gastrocnemius, gluteus maximus, hamstrings, and adductors—were varied, with either six or seven different patterns observed with each muscle (Figs. 5 and 6). These patterns were classified into three groups (types) based on the part of the demi-plié cycle during which the major or maximum activity was present: I, midcycle; II, lowering and/or rising phase; and III, flatline (baseline voltage) tracing (Fig. 5). Analysis of the EMG type data revealed significant differences between ballet and modern dancers for medial gastrocnemius and adductors, with ballet dancers having a higher proportion of types I and II EMG tracings, and moderns type III for both muscles (Table 4). There were no significant differences between ballet and modern dancers in EMG type distribution for lateral gastrocnemius, gluteus maximus, or hamstrings.

For ballet and modern dancers combined, analysis of EMG type data revealed significant differences between muscles. In the majority of demi-pliés, the lateral and medial gastrocnemius EMG tracings were type II (Table 4), with activity primarily in lowering and/or rising

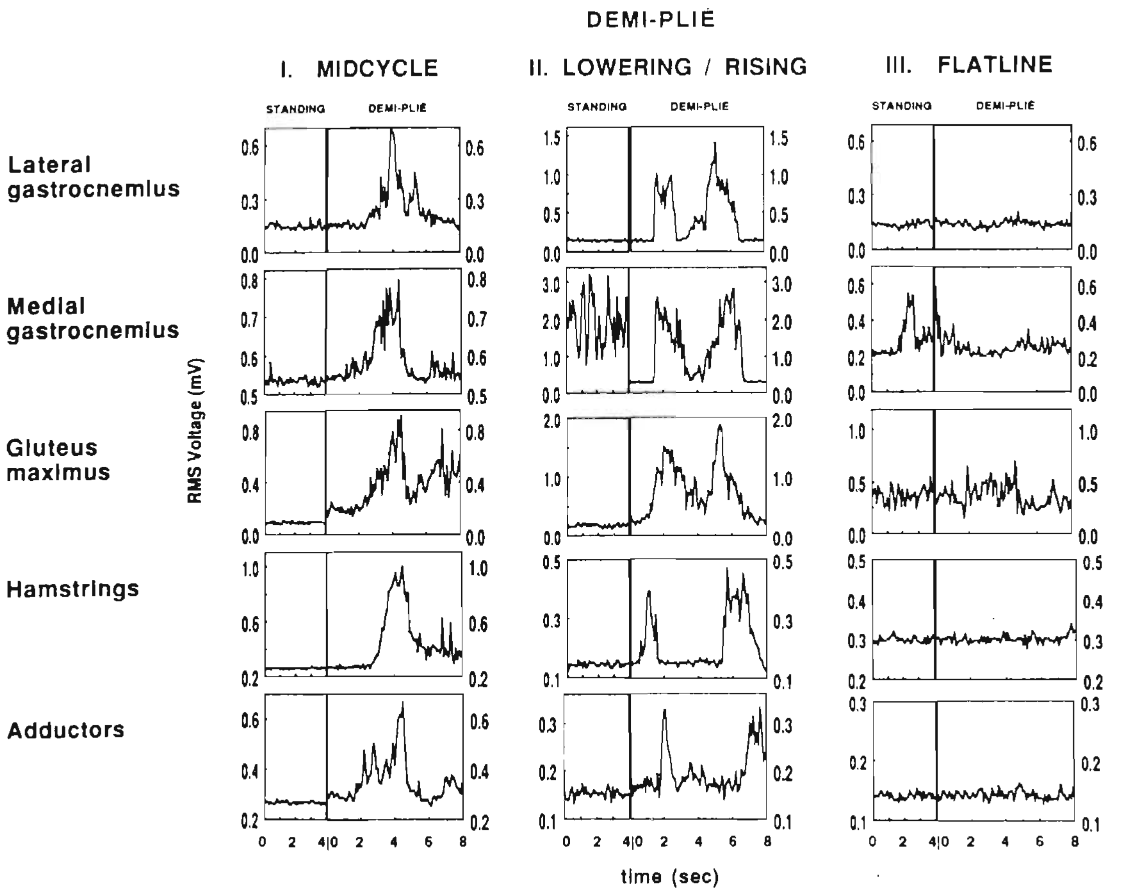

Figure 5—Surface electromyography of lateral gastrocnemius, medial gastrocnemius, gluteus maximus, hamstrings, and adductors during demi-plié. Representative plots of RMS voltage against time during demi-plié are demonstrated adjacent to one of the standing posture EMG plots for the same dancer. EMG plots are grouped into types based on the part of the demi-plié cycle having major or maximum activity: midcycle (I), lowering and/or rising phases (II), or flatline (III). Plots shown for each muscle are, in almost all examples, the most common plot pattern observed for types I, II, and III.

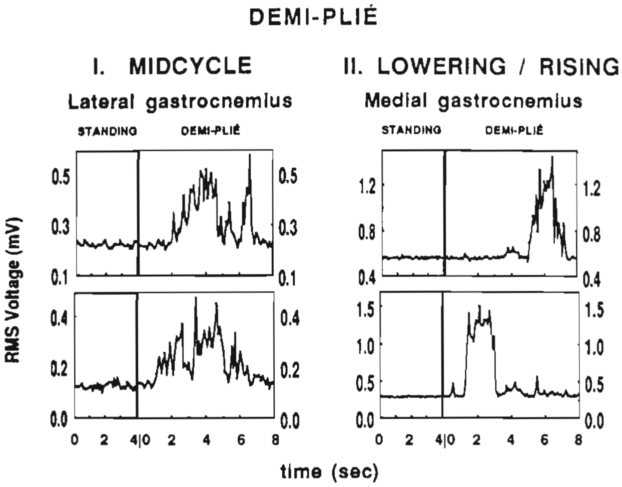

Figure 6—Variation of EMG activity during demi-plié. Type I plots, with activity primarily at midcycle, occasionally included activity during lowering and/or rising phases, as shown for lateral gastrocnemius. Type II plots, with activity primarily during lowering and/or rising phases, occasionally had little or no activity during either of these two phases, as shown for medial gastrocnemius. Variations of the plots shown were observed for both lateral and medial gastrocnemius as well as for gluteus maximus, hamstrings, and adductors.

phases (in contrast with the tibialis anterior, for which primary activity was in midcycle). However, the distribution of EMG plots into types I, II, and III (all dancers) (Table 4) was significantly different between lateral and medial gastrocnemius ($df = 2$, $\chi^2 = 8.72$, $P < 0.025$). Gluteus maximus, hamstrings, and adductors were also significantly different from each other in EMG plot type distribution (gluteus maximus and hamstrings, $df = 2$, $\chi^2 = 16.44$, $P < 0.001$; gluteus maximus and adductors, $df = 2$, $\chi^2 = 6.03$, $P < 0.05$; hamstrings and adductors, $df = 2$, $\chi^2 = 22.57$, $P < 0.001$) (Table 4). Gluteus maximus tracings were almost equally types I (42%) and II (48%) (Table 4). For the hamstrings, EMG tracings were type II in 53% of demi-pliés, but flatline (type III) in one third (Table 4). Tracings from the adductors were type I in 56% of demi-pliés, and flatline in 18% (Table 4).

In all eight muscles tested, variation of EMG plot pattern was observed between the five different demi-plié repetitions of a given subject. For all muscles tested except the tibialis anterior, half or more of all dancers demonstrated more than one plot pattern in the five repetitions; some dancers had three or even four different plot patterns for some of the muscles in the five demi-plié repetitions (Table 5). This variation in plot patterns included differences in the presence or absence of EMG activity before initiating movement or within the phases of demi-plié (Figs. 3–6).

EMG activity in lowering, midcycle, and rising phases. The analysis described in the previous paragraphs provided a description of electrical behavior observed over the entire demi-plié, with emphasis on the relative magnitude of EMG activity present between different phases. However, type I tracings, with dominant activity at midcycle, also had EMG activity in lowering and/or rising phases; conversely, some type II tracings had midcycle activity (Figs. 5 and 6). The presence or absence of EMG activity in each phase is important in the characterization of muscle use in demi-plié. Therefore, the EMG tracings were also graded for the presence or absence of activity in each phase, and the percentage of demi-pliés with activity in each phase was determined (Table 6).

Analysis of these data revealed significant differences between ballet and modern dancers in four of the eight muscles tested (Table 6). EMG activity was significantly more frequent in ballet than modern dancers at midcycle in lateral gastrocnemius, gluteus maximus, and adductors, and during rising phase in medial gastrocnemius and gluteus maximus (Table 6).

For all dancers combined, significant differences were noted between muscles. For both the lateral and medial gastrocnemius, there was EMG activity present in the majority of demi-pliés in lowering and rising phases. In midcycle, 72% of demi-pliés had activity in lateral gastrocnemius, but only 42% in medial gastrocnemius; this difference was significant ($df = 1$, $\chi^2 = 9.82$, $P < 0.005$) (Table 6). In the hamstrings, only 23% of demi-pliés had EMG activity at midcycle. In contrast, the gluteus maximus and adductors had midcycle activity in 68% and 70% of all demi-pliés, respectively; this difference between hamstrings and either of the other two muscles was significant (gluteus maximus, $df = 1$, $\chi^2 = 16.54$, $P < 0.001$; adductors, $df = 1$, $\chi^2 = 22.08$, $P < 0.001$). There was no significant difference between vastus lateralis and medialis; EMG activity was present in both these

TABLE 4. EMG activity in lateral gastrocnemius, medial gastrocnemius, gluteus maximus, hamstrings, and adductors during demi-plié: number (percent) of types I, II, and III EMG tracings.*

	I			II			III			
Muscle†	Ballet	Modern	Total	Ballet	Modern	Total	Ballet	Modern	Total	χ^2, $P <$ §
Lateral gastrocnemius	9 (36%)	14 (40%)	23 (38%)	16 (64%)	19 (54%)	35 (58%)	0 (0%)	2 (6%)	2 (3%)	NS
Medial gastrocnemius	6 (24%)	4 (11%)	10 (17%)	19 (76%)	24 (69%)	43 (72%)	0 (0%)	7 (20%)	7 (12%)	6.4, 0.05
Gluteus maximus	11 (44%)	14 (40%)	25 (42%)	14 (56%)	15 (43%)	29 (48%)	0 (0%)	6 (17%)	6 (10%)	NS
Hamstrings	3 (12%)	5 (14%)	8 (13%)	14 (56%)	18 (51%)	32 (53%)	8 (32%)	12 (34%)	20 (33%)	NS
Adductors‡	12 (60%)	16 (53%)	28 (56%)	8 (40%)	5 (17%)	13 (26%)	0 (0%)	9 (30%)	9 (18%)	8.62, 0.025

* I: maximum activity at midcycle; II: maximum activity at lowering and/or rising phase; III: flatline.

† All muscles except adductors: $N = 25$ (ballet), 35 (modern), 60 (total).

‡ 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.

§ Comparison between ballet and modern dancers, $df = 2$ for all tests; NS (not significant): $\chi^2 < 5.99$, $P > 0.05$.

TABLE 5. Variation in muscle activity in performing five demi-plié repetitions.

Muscle*	Total No. of Different EMG Plot Patterns (All Demi-pliés)‡	Number (percent) of Dancers Demonstrating 1, 2, 3, or 4 Different Patterns of EMG Plots in Five Demi-Plié Repetitions			
		One Pattern	Two Patterns	Three Patterns	Four Patterns
Lateral gastrocnemius	7	5 (42%)	4 (33%)	3 (25%)	0 (0%)
Medial gastrocnemius	6	5 (42%)	5 (42%)	2 (17%)	0 (0%)
Tibialis anterior	2	9 (75%)	3 (25%)	0 (0%)	0 (0%)
Vastus lateralis	5	5 (42%)	5 (42%)	1 (8%)	1 (8%)
Vastus medialis	4	6 (50%)	4 (33%)	2 (17%)	0 (0%)
Gluteus maximus	7	6 (50%)	3 (25%)	3 (25%)	0 (0%)
Hamstrings	6	3 (25%)	5 (42%)	4 (33%)	0 (0%)
Adductors†	6	2 (20%)	4 (40%)	3 (30%)	1 (10%)

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

TABLE 6. EMG activity in lowering phase, midcycle, and rising phase of demi-plié.

Muscle*	Lowering Phase				Midcycle				Rising Phase			
	Ballet	Modern	Total	χ^2, $P <$ ‡	Ballet	Modern	Total	χ^2, $P <$ ‡	Ballet	Modern	Total	χ^2, $P <$ ‡
Lateral gastrocnemius	16 (64%)	18 (51%)	34 (57%)	NS	22 (88%)	21 (60%)	43 (72%)	4.38, 0.05	19 (76%)	29 (83%)	48 (80%)	NS
Medial gastrocnemius	15 (60%)	25 (71%)	40 (67%)	NS	13 (52%)	12 (34%)	25 (42%)	NS	24 (96%)	25 (71%)	49 (82%)	4.40, 0.05
Tibialis anterior	15 (60%)	26 (74%)	41 (68%)	NS	23 (92%)	35 (100%)	58 (97%)	NS	0 (0%)	0 (0%)	0 (0%)	NS
Vastus lateralis	25 (100%)	35 (100%)	60 (100%)	NS	25 (100%)	35 (100%)	60 (100%)	NS	25 (100%)	34 (97%)	59 (98%)	NS
Vastus medialis	25 (100%)	35 (100%)	60 (100%)	NS	25 (100%)	35 (100%)	60 (100%)	NS	25 (100%)	34 (97%)	59 (98%)	NS
Gluteus maximus	15 (60%)	16 (46%)	31 (52%)	NS	24 (96%)	17 (49%)	41 (68%)	12.98, 0.001	25 (100%)	18 (51%)	43 (72%)	14.71, 0.001
Hamstrings	9 (36%)	15 (43%)	24 (40%)	NS	9 (36%)	5 (14%)	14 (23%)	NS	16 (64%)	20 (57%)	36 (60%)	NS
Adductors†	9 (45%)	6 (20%)	15 (30%)	NS	18 (90%)	17 (57%)	35 (70%)	4.86, 0.05	13 (65%)	16 (53%)	29 (58%)	NS

The number (percent) of demi-plié repetitions with activity above baseline is shown for ballet, modern, and all (total) dancers.
* All muscles except adductors: $N = 25$ (ballet), 35 (modern), 60 (total).
† 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.
‡ Comparison between ballet and modern dancers, $df = 1$ for all tests; NS (not significant): $\chi^2 < 3.84$, $P > 0.05$.

muscles in all three phases in almost all 60 demi-plié repetitions (Table 6), except for only one in which there was no activity in rising phase in both muscles.

In rising phase, 60% of demi-pliés had activity in the hamstrings, significantly greater than at midcycle (23%) ($df = 1$, $\chi^2 = 7.58$, $P < 0.01$) (Table 6). Activity in the adductors in rising phase was observed in only 58% of demi-pliés.

The validity of using the three and five repetitions from each subject to form the total number of measurements (N) for standing and demi-plié, respectively, was tested as follows. For each muscle, the standing repetitions and phases of demi-plié repetitions graded as having baseline or increased EMG activity were assigned a numeric value of 0 or 1, respectively. Then, for each muscle, analysis of variance was performed using these values for standing and each phase of demi-plié, and variance within and between subjects compared using F test. In only one case, vastus lateralis during standing, was the variance within greater than that between subjects, but this was not statistically significant (within subjects, $df = 22$, variance $= 0.083$; between subjects, $df = 11$, variance $= 0.068$; $F = 1.22$, $P > 0.05$). 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 pooling of repetitions from the 12 dancers to form the total N is justified.

DISCUSSION

The current study is the first in which muscle activity in standing posture and demi-plié in dancers has been described using electromyography. Standing posture in classical first position with lower extremities turned out was accomplished with minimal EMG activity in the muscles tested except for that detected by the tibialis anterior and medial gastrocnemius electrodes (Table 2). Demi-plié was often initiated with little or no lower extremity EMG activity. As demi-plié progressed, knee flexion in lowering phase, stabilization at midcycle, and extension during rising phase all appeared to be actively controlled by the quadriceps muscles (Fig. 4), as previously observed in nondancers performing a squat movement (2). Activity in the tibialis anterior muscle at midcycle (Fig. 3) was also a characteristic feature of demi-plié as the direction of movement was reversed from lowering to rising.

The marked variation observed during demi-plié in the other muscles tested—lateral and medial gastrocnemius, tibialis anterior during lowering phase, gluteus maximus, hamstrings, and adductors (Figs. 3, 5, and 6)—suggests a secondary, albeit potentially important, role for these muscles in controlling balance and postural sway during the movement. In the previous study of grand battement devant, variation of muscle activity was observed despite similarity in training, performance, and body type of subjects, and it was suggested that each dancer had developed a unique pattern of muscle activity that produced visually similar movement (29). However, the variation of EMG activity in demi-plié was observed not only between different subjects, but also between different repetitions of a given dancer (Table 5). This suggests that factors other than training history or unique personal style, such as balance or postural differences between different repetitions of the same movement, may also modulate the observed activity of these muscles.

The EMG data demonstrate that qualitative anatomic models, which emphasize the contribution of specific muscle groups to dance movement, may be inaccurate and should be reevaluated. The classical image that the adductors are active throughout rising phase in order to maintain turnout (11), or to stabilize the thighs relative to the pelvis, was not applicable to many of the demi-pliés in the present study, as there was no adductor activity observed during rising phase in 42% of demi-pliés (Fig. 5 and Table 6). Thus, certain muscle groups may be currently emphasized in dance training or injury rehabilitation that are not necessarily required for aesthetic, efficient, and safe execution of a specific movement. Furthermore, if a specific muscle group is required for a given movement, a deficiency of strength or flexibility in these muscles may result in compensatory biomechanical errors in technique, which may predispose the dancer to injury (10,26,33). Therefore, the further characterization of specific muscle activity required during dance movements may enable greater anatomic precision in prescribing appropriate directed exercises for dancers in training and rehabilitation who are deficient in certain muscle groups.

The significant differences between ballet and modern dancers in quadriceps activity and genu recurvatum at the end of demi-plié, and the homogeneity within each group, are consistent with the hypothesis that the two groups use these muscles differently because of differences in training and dance style. In nondancers performing a squat, marked variation of quadriceps EMG activity was previously demonstrated at the end of the return to upright standing posture (2). The peak of vastus lateralis and medialis activity at the end of rising phase observed in the ballet group (Fig. 4) (Table 3) is evidence that the genu recurvatum at the end of demi-plié (Fig. 2) is accomplished by active contraction of the quadriceps. The quadriceps EMG activity at the end of rising phase (Fig. 4) continued in ballet dancers even though the subject was no longer moving (Fig. 2), which is evidence that the ballet dancers were contracting the quadriceps to actively maintain genu recurvatum for aesthetic effect. Mild genu recurvatum is a characteristic feature of the "classical ballet line" (10,26,34) and is emphasized in ballet training at the barre (26).

However, some of the differences in muscle activity observed between ballet and modern dancers may have resulted from the significantly different amounts of turnout (7) and genu recurvatum between these groups. Postural instability is potentially greater with larger angles of turnout because the AP component of the longitudinal foot axis in contact with the floor becomes smaller as turnout is increased. This may result in an increased tendency toward postural sway (13,36), which may cause compensatory muscle activity in order to maintain postural stability (13,14,25). Forward and backward sway may result in increased activity of the posterior (calf muscles and hamstrings) and anterior (tibialis anterior and quadriceps) lower extremity muscles respectively (14,25). The ballet dancers may have stood with greater backward sway, possibly because of genu recurvatum and/or greater amount of turnout, resulting in increased incidence of activity in the tibialis anterior (Table 2) (14). In contrast, the modern dancers, who did not stand with genu recurvatum and who do not train with as much emphasis on turnout which is more characteristic of ballet training, had increased incidence of standing EMG activity detected by the medial gastrocnemius electrode, which suggests that they stood with relative forward sway (14).

The amount of turnout may also affect orientation of muscle force vectors, and thereby modulate muscle activity. This is a potential explanation for the observed differences in EMG activity not only between ballet and modern dancers, but also between different muscles. In turned out posture, the lateral gastrocnemius is positioned more posteriorly, and the medial more anteriorly, than in anatomic position, and differences of EMG activity between these muscles, both in standing and demi-plié, may have been a result of this orientation. An alternate explanation for the increased incidence of activity detected by the medial, and not lateral, gastrocnemius electrode in standing posture is that this activity may represent electrical cross-talk from other active medial leg muscles such as the tibialis posterior, flexor digitorum longus, and flexor hallucis longus. A study with standardized amounts of turnout for all subjects may clarify whether the observed differences in muscle activity resulted from differences in turnout, and needle electrode EMG studies (1) may enable identification of the precise muscles of origin of the activity detected by the medial gastrocnemius surface electrode.

The EMG activity observed in the vastus lateralis and medialis just prior to the beginning of many demi-plié repetitions in ballet and modern dancers, and the decrease in this activity upon the start of demi-plié (Fig. 4), is evidence that, when present, it may be specifically related to anticipation of the movement. This activity was not present to as great an extent during the standing posture repetitions, and therefore, cannot be attributed to postural activity alone. Other workers have demonstrated the occurrence of consistent lower extremity postural movements in anticipation of voluntary upper extremity movement (3), and that during the initiation of gait, changes in lower extremity muscle activity occur prior to movement of the swing leg (preparatory period) (4). However, anticipatory quadriceps activity in demi-plié was absent from many repetitions, and the frequency of this activity was similar for both ballet and modern groups, which suggests that this muscle activity is dependent on factors such as habit, balance, posture, and individual variations in technique, and is neither an intrinsic requirement for the movement nor dependent on dance training background.

Further studies of standing posture and demi-plié are necessary to clarify the role of turnout (7), genu recurvatum, training (20,34), and technique (31), as well as additional factors including foot arch structure (7,32,37), forward arm position (14), velocity of movement (23,34), shoewear (15), fatigue (1), and other lower extremity positions used in dance. Other muscle groups may also be important in dance movement, including the foot intrinsics (21), pelvic stabilizers, paraspinals, and abdominals (30,33). Studies using force platforms and pedobarography (22) may clarify the contributions of body forces and pedal pressures to muscle activity observed with EMG analysis. A nondancer control group would also be useful in the characterization of the effects of training (20). Nevertheless, the current study is the first objective demonstration of differences in movement patterns between ballet and modern dancers, and is a starting point from which specific muscle activity in the dancer's standing posture and demi-plié can be further analyzed.

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