Electromyographic Comparison of *Grand Battement Devant* at the *Barre*, in the Center, and Traveling

Donna Krasnow, MS, Jatin P. Ambegaonkar, PhD, ATC, M. Virginia Wilmerding, PhD, Shane Stecyk, PhD, ATC, Yiannis Koutedakis, PhD, Matthew Wyon, PhD

This study examined utilization of the trunk and lower extremity muscles during *grand battement devant* in three conditions: at the *barre* (supported stationary condition in 1st position), in the center (unsupported stationary condition in 1st position), and traveling through space. Forty dancers (age 30.0 ± 13.0 yrs, height 1.63 ± 0.06 m, weight 59.0 ± 7.4 kg, and 13.9 ± 13.3 yrs of training in ballet and/or modern dance) volunteered and were placed in three skill level groups: beginner (n = 12), intermediate (n = 14), and advanced (n = 14). Dancers executed five *grand battement devant* in each of the three conditions in randomized order. We examined muscle activation bilaterally in eight muscles (abdominals, abductor hallucis, erector spinae, gastrocnemius, gluteus maximus, hamstrings, quadriceps, and tibialis anterior) using surface electromyography, a three-dimensional video biomechanical tracking system to identify events, and force plates. All data were analyzed in four events: stance, initiation, peak, and end. Analysis was done using a linear mixed effects regression model with condition, event, muscle, level, and side as the fixed effects, and subject as the random effect. There were significant effects for muscle × event × condition ($p<0.01$) and for level × side × muscle ($p<0.01$). Muscle use varied according to the combination of event and condition that was executed, and these differences were also influenced by the level of training of the dancer and the side of the body used. It is recommended that dance educators consider the importance of allocating sufficient time to each of the three conditions (*barre*, center, and traveling) to ensure development of a variety of motor strategies and muscle activation levels for dance practice. *Med Probl Perform Art* 2012; 27(3):143–155.

Dancers in classical ballet and contemporary dance train in a variety of conditions including floor work, *barre* work, center practice, and traveling. The *barre* has been the subject of dance research dating back to the late 1970s.[1,2] The biomechanical studies comparing work at the *barre* and in the center suggest that dancers work differently in these two conditions.[1,3–7] Other noted researchers have hypothesized that there are differences between muscle activation and motor control strategies at the *barre* and in the center.[2,8,9] Dance educators often assume that there is positive transfer of training from the *barre* to center practice in dance training.[10] In motor control research, Cordo and Nashner[11] found that when the trunk was supported by a bar while performing arm movements that should disturb equilibrium, the lower extremity and trunk postural reflexes did not respond. It is currently unknown whether there is enough similarity between the muscular and biomechanical aspects of movements at the *barre* and center to encourage positive transfer between the two conditions. If in fact there is dissimilarity, and dance educators spend extensive time during dance classes at the *barre*, it may interfere with aspects of motor control of dance movements during center and traveling practice.

Other dance research has focused on the profiling of elite dancers, and comparisons between elite dancers and novice or nondancers.[1,12–28] Differences between groups include variability of muscle use,[15,18] anticipatory postural strategies,[21,22] and muscle amplitude.[16,27] Similarities between groups include reaction time in certain balancing tasks[23] and responses to fatigue.[28] If in fact there are aspects of dance practice that are similar across all levels of training, it might suggest that these elements of dance movement do not need attention in dance class for enhanced ability. One might even propose that these aspects cannot be affected by training, regardless of years of practice or training approaches.

One of the questions raised by dance educators and somatic practitioners involves the issue of movement efficiency, and they propose the idea that elite dancers are more efficient in movement execution than novices. However, there is insufficient research to date to clarify whether this is the case, or even what efficiency would entail. Efficiency might suggest that elite dancers use less effort in the involved muscles, or it could mean that they use fewer muscles to achieve the task. For example, EMG studies of the *plié* have compared muscle use of advanced and beginning dancers,[16] ballet and modern dancers,[29,30] and dancers with and without knee pain.[31] Ferland, Gardener, and Lèbe-Néron[16] concluded that advanced dancers had significantly lower biceps femoris activation at initiation of flexion and extension of *demi plié* than beginners, and they had significantly lower rectus femoris activation at the end of the flexion phase than

Ms. Krasnow is Professor, Department of Dance, Faculty of Fine Arts, York University, Toronto, Ontario, Canada, and Lecturer, Department of Kinesiology, California State University, Northridge, California, USA; Dr. Ambegaonkar is Director, Sports Medicine Assessment, Research, and Testing (SMART) Laboratory, and Coordinator, Exercise, Fitness, and Health Promotion (EFHP) Graduate Program, Athletic Training Education Program (ATEP), George Mason University, Manassas, Virginia, USA; Dr. Wilmerding is Adjunct Professor, Department of Dance, and Assistant Research Professor, Department of Health, Exercise & Sports Sciences, University of New Mexico, Albuquerque, New Mexico, USA; Dr. Stecyk is Director, Athletic Training Education Program, Department of Kinesiology, California State University, Northridge, California, USA; and Dr. Koutedakis and Dr. Wyon are Professors with the Research Centre for Sport, Exercise and Performance, School of Sport, Performing Arts and Leisure, University of Wolverhampton, Walsall, UK; Dr. Koutedakis is also with the Department of Exercise Sciences, University of Thessaly, Trikala, Greece, and the Institute of Human Performance and Rehabilitation, CERETETH, Trikala, Greece; and Dr. Wyon is also with the Department of Dance, Artez, Arnhem, The Netherlands.

Address correspondence to: Donna Krasnow, Department of Dance, ACE 313, York University, 4700 Keele Street, Toronto, ON M3J 1P3, Canada. Tel 416-736-5137 x22130, fax 416-736-5743. dkrasnow1@aol.com.

TABLE 1. Subject Demographics by Training Level

Level	*n*	Height (m)	Weight (kg)	Years Training	Age (yrs)
Beginners	12	1.62 ± 0.07	59.9 ± 8.4	1.5 ± 0.5	23.0 ± 4.5
Intermediates	14	1.63 ± 0.05	59.6 ± 7.6	11.9 ± 9.6	26.0 ± 12.0
Advanced	14	1.65 ± 0.07	57.6 ± 6.7	26.4 ± 11.3	40.0 ± 14.0
All combined	40	1.63 ± 0.06	59.0 ± 7.4	13.9 ± 13.3	30.0 ± 13.0

the beginners. However, an intervention study by Couillandre, Lewton-Brain, and Portero[32] revealed that the use of the biceps femoris increased post-training and was correlated with less "bucking" in the spine during jumps.

The most recent literature review of dance biomechanics studies has identified the *grand battement* as the subject of one the earliest biomechanics investigations in the dance literature.[33] Ryman and Ranney[2] collected data on the *grand battement devant* in the center without support, using single-camera cinematography. Although they did not collect data at the *barre*, they claimed through anecdotal observation that there is less weight shift to the supporting leg during the *battement* at the *barre* than in the center. Similarly, Laws[8] proposed that the *barre* allows for forward shift of the torso in arabesque and provides torso stabilization for movements such as *rond de jambe* that are not possible without the *barre*; he questions whether this work is transferrable to center practice. Bronner and Ojofeitimi[13] did extensive profiling using kinematic data of elite dancers executing *grand battement devant*, *à la seconde,* and *derrière*, and found large pelvic movements in all three planes to accommodate hip joint movement. However, there is no comparative data in the center or traveling, and therefore, it is not possible to know whether elite dancers perform these movements with similar strategies when unsupported.

In summary, the dance biomechanics research to date suggests: (1) there are important differences between some aspects of movement performed at the *barre* and in the center, including weight shift strategies, muscle activation, joint torque, and dynamic alignment; (2) dancers rely on the *barre* in some aspects of movement organization regardless of level of training; and (3) there is high variability in muscle activation when comparing *barre* work and center practice, and when comparing dancers of various levels of training. To date, no dance research has compared *barre* and center work to dance movement traveling in space, and determined whether this third condition is biomechanically different from the other two.

If dance educators are to be effective in preparing dancers for the performance of dance repertoire, it would be useful to understand which aspects of training are transferrable from *barre* to center and from center to travelling, and in what ways elite dancers differ from novice dancers. Similarly, medical practitioners working in the field of dance injury rehabilitation could benefit from this knowledge and improve strategies for preparing dancers to return to full function.

Therefore, the purpose of this study was to examine *grand battement devant* in three conditions: at the *barre*, in the center, and traveling through space. The first hypothesis was that utilization of the trunk and lower extremity muscles in the *grand battement devant* would differ during the three conditions. The second hypothesis was that there would be differences in muscle activation levels between dancers of various training levels.

METHODS

Participants

Dancers were recruited for the study through announcements in university dance classes and postings in professional dance email listservs and local newsletters. Forty-three female dancers volunteered for the study. Inclusion criteria included enrollment in a university level dance class or in a professional dance studio or training program and exposure to ballet and/or modern dance. Exclusion criteria included a history of confounding medical problems or a current injury impacting on the execution of the dance task for the study. The study was approved by the Standing Advisory Committee for the Protection of Human Subjects at California State University, Northridge, and all participants gave informed written consent. One volunteer arrived with a recent injury and was excluded from the study. Data for two participants had to be eliminated from analysis due to lost data during collection.

The remaining 40 participants had a mean age of 30.0 ± 13.0 yrs, mean height of 1.63 ± 0.06 m, mean weight of 59.0 ± 7.4 kg, and an average of 13.9 ± 13.3 yrs of training in ballet and/or modern dance. The three levels for the study were defined by two dance experts as follows: (1) beginning dancers (n = 12) had less than 2 years of training, average 1.5 yrs; (2) intermediate dancers (n = 14) had more than 2 years of training, average 11.9 yrs, and no professional (paid) dance experience; (3) advanced dancers (n = 14) had 10 or more years of training, average 25.5 yrs, and professional (paid) dance experience. Dance experience included ballet, modern and contemporary dance, jazz, hip hop, break or street dance, musical theater, tap dance, and various world dance forms. Dancers from various professional dance companies were included. Table 1 shows the demographics of the subjects by training level.

Instrumentation

Surface electrodes (DE 2.3, Myomonitor Single Differential Ag electrodes, skin contact size 10 × 1 mm, center-to-center distance of 10 mm) were applied over the skin after it was prepped with alcohol. Electrode placements were based on the SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) Project standards (http://www.seniam.org). The electrodes were placed on the body in the following order:

Supine: quadriceps (QA), tibialis anterior (TA), abductor hallucis (AH);
Prone: gastrocnemius (GA), biceps femoris (HAM), gluteus maximus (GM), erector spinae (ES); and
Standing: rectus abdominus (ABS).

This order required the least amount of participant movement, which limited the possibility of electrode disturbance during the process. The decision to collect data on the AH was based on previous research findings.[7]

All sEMG data were collected using a combination of a 16-channel Myomonitor IV wireless transmitter (Delsys Inc., Boston, MA) with an operating range of 250 m, preamplifier gain 1000 V/V with a frequency bandwidth of 20-450 Hz, a common mode rejection ratio of 92 dBmin at 60 Hz and an input impedance >1015 Ω//0.2 pF, and the Vicon Nexus 1.416 system (Centennial, CO, USA). The electrode wires were wrapped around the Myomonitor belt to eliminate excess wiring that might interfere with movement. Data for maximum voluntary isometric contractions (MVICs) were collected with a portable anchoring dynamometer system developed for the purposes of this study.[34] Kinetic data were collected with two Kistler force plates (9287A, 9287BA) (Kistler Instruments, Inc., Amherst, NY) at 960 Hz. Kinematic data were collected using a 7-camera Vicon MX Ultranet motion capture system (Oxford Metrics Ltd, Oxford, UK), sampled at 240 Hz.

Protocol

All participants wore sports bras and elastic shorts during testing and completed all trials in bare feet. After surface electrodes were placed on the body, dancers completed a self-selected warm up of 15 minutes, followed by the MVIC collection, using previously published methods.[34] Dancers were then given a 15-minute resting interval and a second warm-up period before the movement trial procedure was explained. Trials at the *barre* and in the center were executed in the dancer's preferred first position (lower extremities externally rotated). All trials were conducted with the right leg as the gesture leg. Dancers performed five trials at the *barre* in 1st position with the left hand at the *barre*, five trials in the center in 1st position, and five trials traveling. All participants followed the same randomized order and were provided with 1-minute rest periods between trials.

First position was used at the *barre* and in the center, as it allowed for a more direct comparison between the three conditions. For *barre* and center trials, dancers were instructed to hold the final stance position until instructed by the researchers to rest. Traveling trials included two steps (right, left) prior to the *battement*, and two steps (right, left) after the *battement*. Steps were executed in *plié* at a depth of the dancer's choice, and dancers were instructed to take the first step onto force plate 1 and the second step onto force plate 2, with the final two steps clearing the force plate area. While these instructions permitted some variance due to height and leg length, the size of the force plates encouraged large steps. In essence, the traveling condition simulates the preparation for a *grand jeté*. Trials were executed in time to a recording of the music titled "Dance of the Knights" from the ballet *Romeo and Juliet* by Sergei Prokofiev at a tempo of 104 beats per minute. At the *barre*, the left hand was resting on the *barre* and the right arm was in classical second position. For the center and traveling trials, both arms were in classical second position.

Definitions of Events

Reflective markers were placed on the participants' feet (heel and toe) in order to identify biomechanical events using the three-dimensional video system and force plates, as described in previously published methods.[35]

For the *barre* and center conditions, the events were defined as follows:

1. *Stance (STN)* was 120 samples or frames (0.5 sec) prior to the *grand battement* initiation (GBI).
2. *Grand Battement Initiation (GBI)* was the point in time when the velocity of the right heel marker started moving in the forward (y-axis) direction. When the y-component of first derivative (velocity) of the right heel was greater than 0, it indicated that the right heel was moving in the forward direction.
3. *Grand Battement Peak (GBP)* was the highest point in the z-axis for the right toe marker.
4. *End (END)* was 120 samples or frames (0.5 sec) after the point in time when the weight shifted from being entirely on the left foot back onto the right foot after the *grand battement.*

For the traveling condition, the events were defined as follows:

1. *Stance (STN)* was the point in time when all of the weight was transferred onto the left foot prior to the *grand battement*, marked by toe-off on the back force plate (force plate 1). At this point the right leg was behind the left leg but was not weight-bearing.
2. *Grand Battement Initiation (GBI)* was the point in time when the right heel passed the left heel in the y-direction, as the right leg moved forward to initiate the *battement*.
3. *Grand Battement Peak (GBP)* was the highest point in the z-axis for the right toe marker.
4. *End (END)* was 120 samples or frames (0.5 sec) after the point in time when the weight shifted entirely off the left foot onto the right foot after the *grand battement*, marked by toe-off on the front force plate (force plate 2).

Statistical Analyses

Data for the analyses were computed by dividing muscle output data by the MVIC (maximum voluntary isometric contraction) for each muscle for each participant. For example, 0.48 indicated that the participant used 48% of her maximum during that movement.

In order to identify which data points needed to be removed from the sample due to measurement error and/or too much influence as an outlier, the Mahalanobis distance was utilized. The Mahalanobis distance is best for non-inde-

TABLE 2. Muscle Activation Variables for All Muscles, Events, and Conditions in All Participants*

Variable		Average Score	SD		Average Score	SD
Muscle	L ABS	0.21	0.20	R ABS	0.27	0.43
	L AH	0.49	0.62	R AH	0.27	0.30
	L ES	0.12	0.16	R ES	0.12	0.13
	L GA	0.47	0.34	R GA	0.24	0.31
	L GM	0.35	0.50	R GM	0.10	0.10
	L HAM	0.26	0.25	R HAM	0.11	0.09
	L QA	0.27	0.23	R QA	0.34	0.32
	L TA	0.24	0.18	R TA	0.14	0.13
Event	Stance	0.15	0.17			
	Initiation	0.23	0.21			
	Peak	0.30	0.25			
	End	0.18	0.19			
Condition	Barre	0.16	0.18			
	Center	0.18	0.15			
	Travel	0.31	0.25			

*All muscle activation data are expressed as a percentage of maximum voluntary isometric contractions: rectus abdominus (ABS), abductor hallucis (AH), erector spinae (ES), gastrocnemius (GA), gluteus maximus (GM), biceps femoris (HAM), quadriceps (QA), and tibialis anterior (TA); left side (L), right side (R).

pendent data as in this study, as it takes into account the covariance among the variables and measures the distance in three dimensions.[36] A chi-squared test was used to remove all data points with a statistically significant result as outliers. With this criterion, 200 data points were removed from the sample of 7680 data points.

The hypotheses were tested using a linear mixed effects regression model, which included muscle utilization as the dependent variable. The main covariate included in this model was condition. Variables for muscle, event and training were also included as covariates. An indicator variable for side was included as a control variable. Although differences between left and right sides were not one of the research questions in this study, side needed to be included as a control variable due to varying roles of the muscles tested for the standing leg versus the gesture leg. Since these measures were taken from a sample of 40 dancers, the points do not meet the assumption of independence of errors. To account for this, the data were analyzed using a linear mixed effects regression model. As the distribution of the dependent variable did not meet the normality assumption, the analysis was conducted using the log of the dependent variable.

The linear mixed effects regression model included all the covariates as fixed effects and subject ID as the random effect. A random slope for each subject was also retained in the model. The correlation of the random effects was modeled using an unstructured correlation matrix. The parameter estimation was done using the restricted maximum likelihood (REML) and the model selection process was done using the maximum likelihood. The model that best fit the data and answered the research question was the model that predicted the dancer's muscle use using the fixed effects of a three-way interaction of muscle × event × condition and a three-way interaction of level × side × muscle. To test the significance of the individual parameters and the effects of their interactions, we conducted Wald tests using a two-side t-distribution. Significance was set at $p \leq 0.05$.

Results

Table 2 shows muscle activation variables for all muscles, events, and conditions in all participants.

Table 3 shows the muscle activation for all levels of training by muscle in all events. Both Table 2 and Table 3 illustrate that the standard deviations (SD) are relatively large in our data. This is an indication that there is a large amount of variation between dancers. We controlled for these differences between individuals within our model, and it should also be noted that our results are generalizations and that individual dancers are all unique.

It is clear from the model that the way a dancer uses the muscles varies according to the combination of event and condition being executed. There was a significant effect for muscle × event × condition, $p<0.01$. Thus, how the dancer uses each muscle is significantly different in each event, and how the dancer uses each muscle within that event is significantly different in each condition. Additionally, there was a significant effect for level × side × muscle, $p<0.01$. Therefore, the differences are influenced by the level of training of the dancer and the side of the body being used.

Table 4 shows the *p*-values for each muscle by condition and by event for all participants. This table shows the results of the linear mixed-effects model described in the Statistical Analyses section. It reflects the results of the regression model that tests how muscle use varies by each condition. Since the model includes covariates for condition, muscle, and event, we present the estimates of muscle use in each combination of muscle by condition by event in order to illustrate the effects

TABLE 3. Muscle Activation for All Levels of Training by Muscle in All Events

		Beginner		Intermediate		Advanced	
Muscle	Event	Average Score	SD	Average Score	SD	Average Score	SD
ABS	Stance	0.18	0.19	0.15	0.20	0.18	0.17
	Initiation	0.25	0.22	0.22	0.26	0.26	0.24
	Peak	0.25	0.19	0.23	0.25	0.26	0.20
	End	0.21	0.20	0.17	0.21	0.21	0.15
AH	Stance	0.28	0.24	0.20	0.23	0.25	0.22
	Initiation	0.43	0.30	0.26	0.24	0.33	0.27
	Peak	0.50	0.28	0.32	0.29	0.40	0.27
	End	0.36	0.26	0.20	0.20	0.30	0.24
ES	Stance	0.10	0.10	0.08	0.09	0.12	0.14
	Initiation	0.12	0.16	0.09	0.07	0.14	0.13
	Peak	0.17	0.16	0.14	0.16	0.24	0.27
	End	0.07	0.07	0.06	0.06	0.08	0.06
GA	Stance	0.14	0.21	0.15	0.21	0.20	0.24
	Initiation	0.23	0.21	0.14	0.16	0.21	0.20
	Peak	0.30	0.26	0.23	0.23	0.40	0.26
	End	0.15	0.19	0.11	0.13	0.24	0.23
GM	Stance	0.10	0.11	0.09	0.10	0.13	0.17
	Initiation	0.21	0.27	0.17	0.23	0.20	0.25
	Peak	0.23	0.21	0.23	0.23	0.30	0.28
	End	0.14	0.19	0.14	0.24	0.17	0.23
HAM	Stance	0.13	0.12	0.11	0.10	0.13	0.10
	Initiation	0.20	0.18	0.16	0.17	0.20	0.20
	Peak	0.27	0.21	0.26	0.22	0.31	0.26
	End	0.14	0.18	0.11	0.12	0.14	0.15
QA	Stance	0.19	0.16	0.16	0.12	0.27	0.19
	Initiation	0.20	0.18	0.18	0.12	0.27	0.18
	Peak	0.39	0.26	0.37	0.23	0.54	0.34
	End	0.23	0.25	0.24	0.24	0.35	0.27
TA	Stance	0.08	0.08	0.11	0.10	0.10	0.08
	Initiation	0.22	0.17	0.22	0.18	0.26	0.18
	Peak	0.24	0.18	0.22	0.17	0.28	0.20
	End	0.11	0.10	0.14	0.16	0.12	0.10

of each combination and its statistical significance. Table 4 has been designed to illustrate overall differences in muscle usage by condition and event and does not show differences between sides or levels. Each event (stance, initiation, peak, and end) will be discussed separately.

Figures 1 to 8 display the graphs of each muscle (left and right sides) for the four events and three conditions. These figures have been simplified to show overall trends in muscle usage for each muscle by side and condition and do not illustrate differences by level. Figure 9 displays the four events (stance, initiation, peak, and end) for the traveling condition.

Stance: Muscle × Event × Condition

In the stance event, most of the significant differences were found between traveling and the other two conditions. There were significant differences for ES, HAM, QA, and TA between *barre* and traveling, and between center and traveling. There were significant differences between all three conditions for AH and for GA. For ABS, there was a significant difference only between *barre* and traveling. For GM, there were no significant differences between any of the three conditions. See Table 4 for *p*-values for all of the significance levels.

Initiation: Muscle × Event × Condition

For all muscles tested, there were significant differences in the initiation event between *barre* and traveling, and between center and traveling. There were no significant differences for any muscles in this event for *barre* and center. See Table 4 for *p*-values for all of the significance levels.

Peak: Muscle × Event × Condition

As with the stance event, most of the significant differences in the peak event were found between traveling and the other two conditions. There were significant differences between *barre* and traveling, and between center and traveling for ES, GM, HAM, and TA. There were significant differences between all three conditions for AH and GA. For ABS and

TABLE 4. Results of Analysis of Muscle × Condition × Event in All Participants

Muscle	Condition	Events (p-values)			
		Stance	Initiation	Peak	End
ABS	Barre to center	0.71	0.98	0.86	0.38
	Barre to traveling	0.03	0.03	0.07	<0.00001
	Center to traveling	0.06	<0.00001	0.11	<0.00001
AH	Barre to center	0.01	0.42	<0.01	0.01
	Barre to traveling	<0.00001	<0.00001	<0.00001	<0.00001
	Center to traveling	<0.01	<0.00001	<0.00001	<0.01
ES	Barre to center	0.07	0.79	0.23	0.80
	Barre to traveling	<0.00001	<0.00001	<0.00001	0.16
	Center to traveling	<0.00001	<0.00001	<0.00001	0.10
GA	Barre to center	0.03	0.55	0.02	0.04
	Barre to traveling	<0.00001	<0.00001	<0.00001	<0.00001
	Center to traveling	0.01	<0.00001	<0.00001	<0.01
GM	Barre to center	0.76	0.51	0.46	0.24
	Barre to traveling	0.71	<0.00001	<0.00001	<0.00001
	Center to traveling	0.50	<0.00001	<0.01	<0.00001
HAM	Barre to center	0.25	0.91	0.12	0.20
	Barre to traveling	<0.00001	<0.00001	<0.00001	<0.00001
	Center to traveling	<0.01	<0.00001	<0.00001	<0.01
QA	Barre to center	0.92	0.69	0.69	0.25
	Barre to traveling	<0.00001	<0.00001	0.53	<0.00001
	Center to traveling	<0.00001	<0.00001	0.81	<0.00001
TA	Barre to center	0.93	0.43	0.86	0.38
	Barre to traveling	0.04	0.04	0.04	<0.01
	Center to traveling	0.04	0.03	0.04	0.01

Rectus abdominus (ABS), abductor hallucis (AH), erector spinae (ES), gastrocnemius (GA), gluteus maximus (GM), biceps femoris (HAM), quadriceps (QA), and tibialis anterior (TA).

for QA, there were no significant differences between any of the three conditions. See Table 4 for *p*-values for all of the significance levels.

End: Muscle × Event × Condition

As with the previous events, most of the significant differences in the end event were found between traveling and the other two conditions. There were significant differences between *barre* and traveling, and between center and traveling for ABS, GM, HAM, QA, and TA. There were significant differences between all three conditions for AH and GA. For ES, there were no significant differences between any of the three conditions. See Table 4 for *p*-values for all of the significance levels.

Training levels

There were significant differences in muscle use between beginner and intermediate dancers for AH and ES. There were significant differences in muscle use between beginner and advanced dancers for AH, GA, and QA. Significant differences were also observed in muscle use between intermediate and advanced dancers for ABS, AH, ES, GA, QA, and TA. See Table 5 for the *p*-values for muscle activation by level of training.

DISCUSSION

The purpose of this study was to examine muscle activation levels during the *grand battement devant* in three conditions: at the *barre*, in the center, and traveling. The primary focus was to compare muscle use of the trunk and lower extremity muscles during the battement across the three conditions. Additionally, the study explored whether or not there are significant differences between dancers of various training levels. Each event (stance, initiation, peak, and end) is evaluated separately and followed by a discussion of an overview of each muscle and a comparison of the three training levels.

Stance: Muscle × Event × Condition

With the exception of the GM, all muscles were used differently during the traveling condition than at the *barre* or in the center in the stance event. For ABS, muscle activation was actually at a lower percentage of maximum when traveling than at the *barre*, but ABS did not differ significantly between *barre* and center or between center and traveling. However, for ES, HAM, and TA, muscle use was at a greater percentage of maximum for traveling than for *barre* and center, and these differences were significant. For QA, as with ABS, muscle use was dramatically lower for traveling,

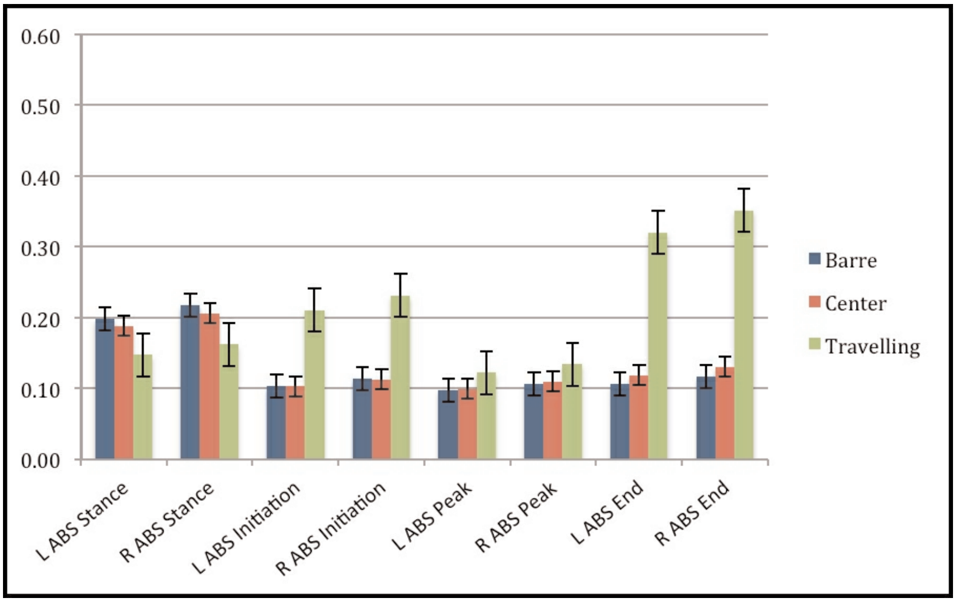

FIGURE 1. Abdominals (left and right) by condition by event

and was significantly different from both *barre* and center. The only two muscles that demonstrated differences between all three conditions were AH and GA, and activation increased from *barre* to center and from center to traveling.

It is interesting to note that the ankle strategy for balancing mechanisms described by Cordo and Nashner[11] starts with activation of the TA and GA at the moment of loss of equilibrium, and this study was done in natural (parallel) stance. It may be the case that the AH takes over some of the anterior postural adjustment when the legs are in external rotation. Another noteworthy observation is the lower muscle activation of the right GM compared to the left GM in the stance phase even though no movement initiation has begun. The GM is already favoring the standing (left) leg in all three conditions. Perhaps the GM is stabilizing the stance hip to accept the full body weight in single-legged balance in preparation for the *battement*.

Initiation: Muscle × Event × Condition

In the Initiation event, *barre* and center had no significant differences for all muscles tested, but traveling was significantly

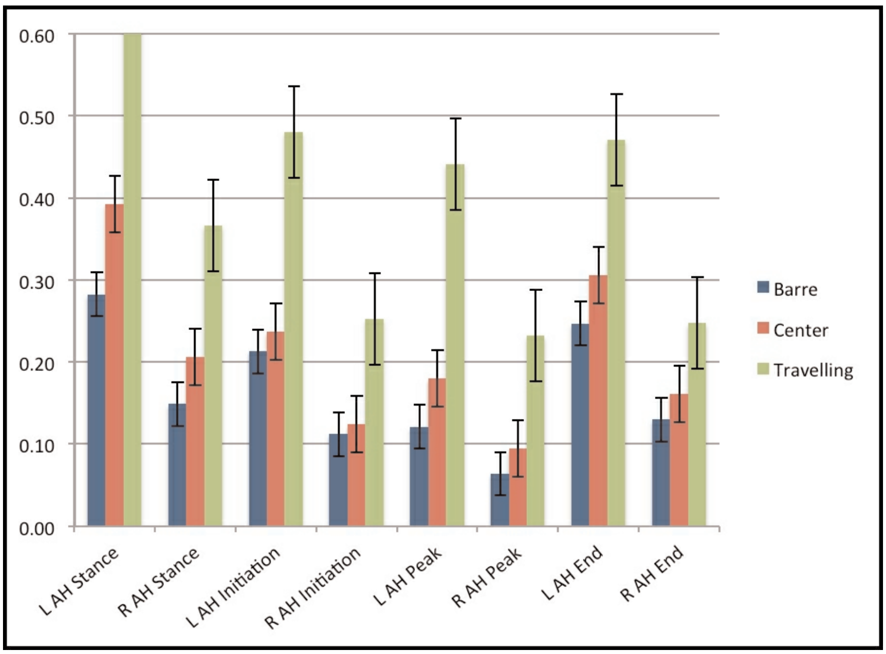

FIGURE 2. Abductor hallucis (left and right) by condition by event

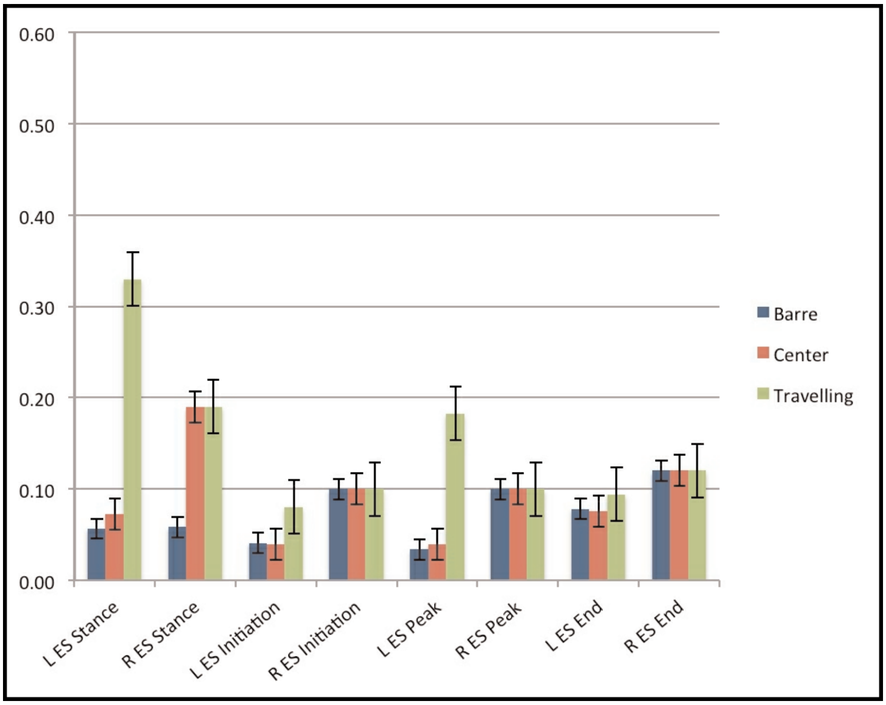

FIGURE 3. Erector spinae (left and right) by condition by event

different from the other two conditions for all muscles. The muscles increased activation from stance to initiation, and the change for QA in the traveling condition mirrored the sharp decrease in this muscle in the traveling condition at stance when compared to *barre* and center. Clearly, differences in muscle use between the two conditions (*barre* and center) is not demonstrated at the moment of initiation in the *grand battement* even though strategies for transferring the weight from two feet to one at the moment of initiation have been demonstrated to be significantly different for *barre* and center.[35] It may be the case that upper extremity muscles are involved at the *barre* to accommodate weight transfer, or that lower extremity and trunk muscles not tested, such as hip adductors, participate at the initiation of weight transfer.

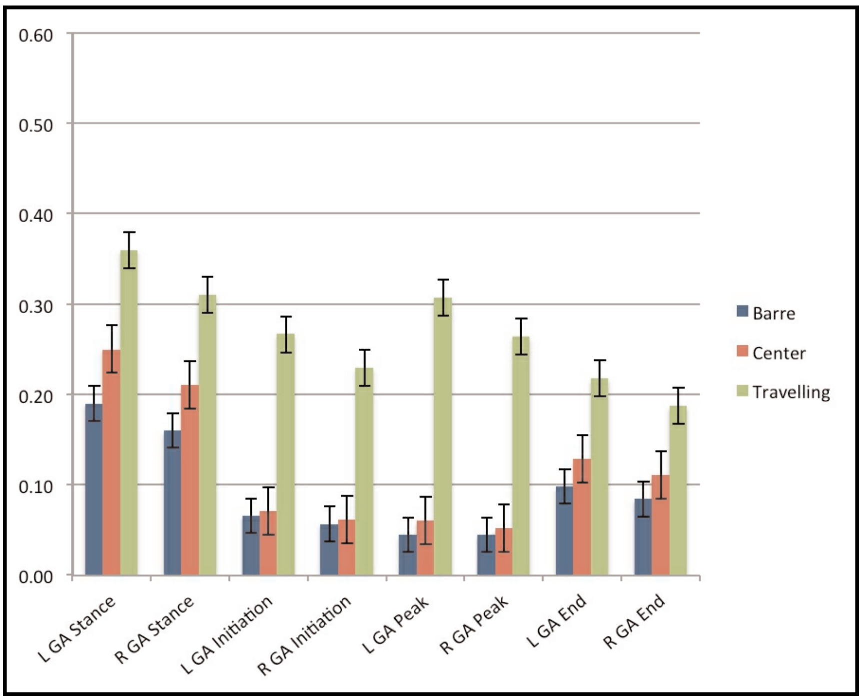

FIGURE 4. Gastrocnemius (left and right) by condition by event

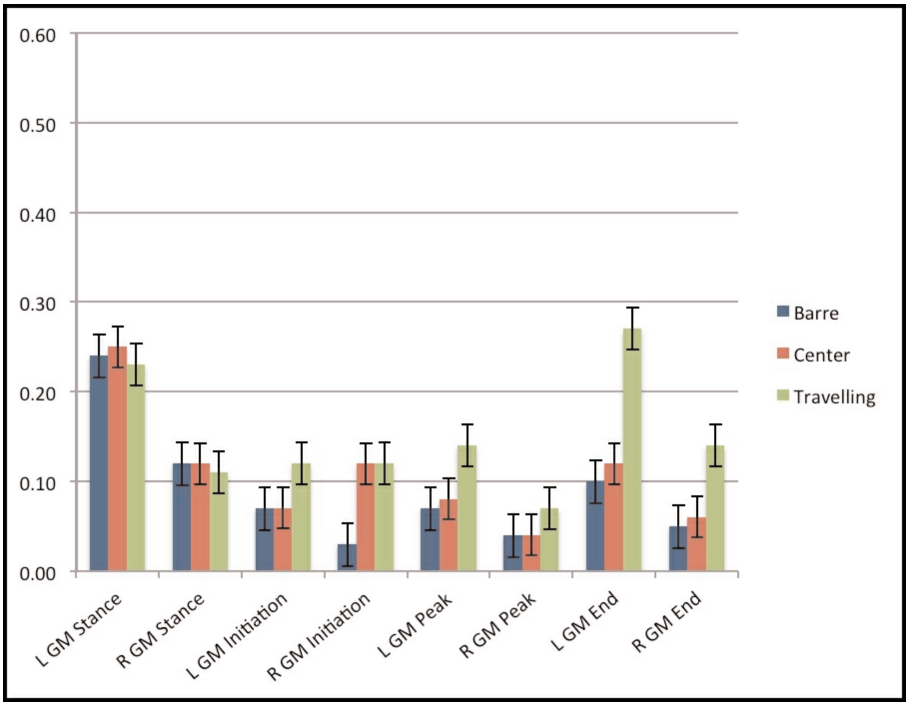

FIGURE 5. Gluteus maximus (left and right) by condition by event

Peak: Muscle × Event × Condition

In the peak event, the graphs of both ABS and QA appear in the plots as flat lines across the three conditions, meaning there is essentially no difference across conditions in the use of these two muscles at the peak of the *battement* (see Figures 1 and 7). As with stance, ES, HAM, and TA all increased in activation from *barre* to traveling and from center to traveling, but did not demonstrate significant differences between *barre* and center. And once again, the two muscles demonstrating significant differences between all three conditions are AH and GA, the lower leg muscles that may be contributing to ankle strategy balancing mechanisms, as previously discussed.

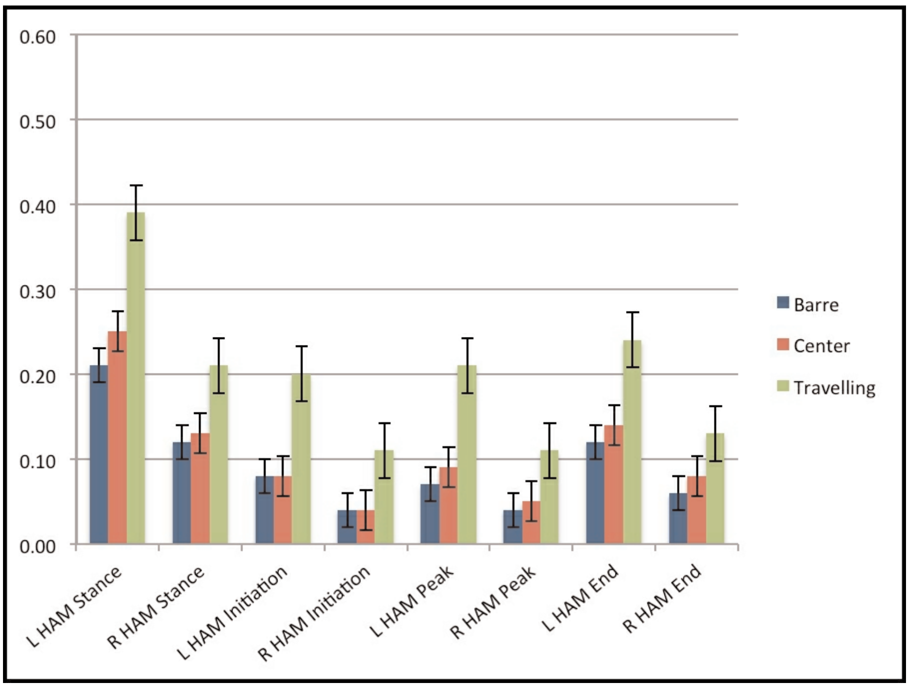

FIGURE 6. Hamstrings (left and right) by condition by event

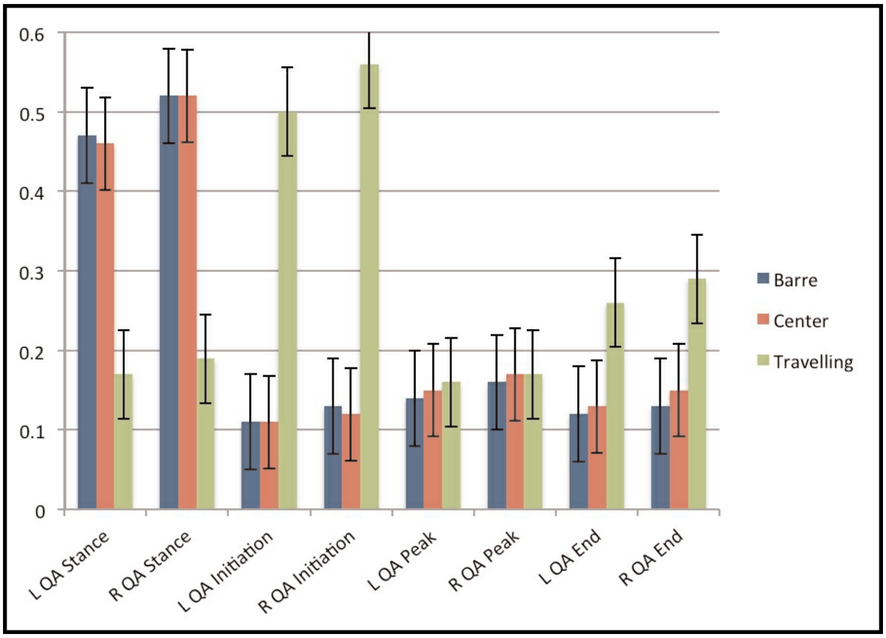

FIGURE 7. Quadriceps (left and right) by condition by event

End: Muscle × Event × Condition

The only muscle that had no differences between conditions in the end event was ES, appearing as a flat line on the graph (see Figure 3). For ABS, GM, HAM, QA, and TA, there are significant differences between *barre* and traveling and between center and traveling. Muscle activation levels increased across the three conditions (*barre* to center to traveling), although there was no significant difference between *barre* and center. As in both stance and peak, both AH and GA showed significant differences for all three conditions. Clearly, these two lower leg muscles are the muscles that change activation levels from *barre* to center to traveling, increasing with each change of difficulty level regarding balancing strategies. The graphs of the right and left AH exhibit pronounced increases in this event, from one condition to the next, particularly for the left (standing) leg (see Figure 2).

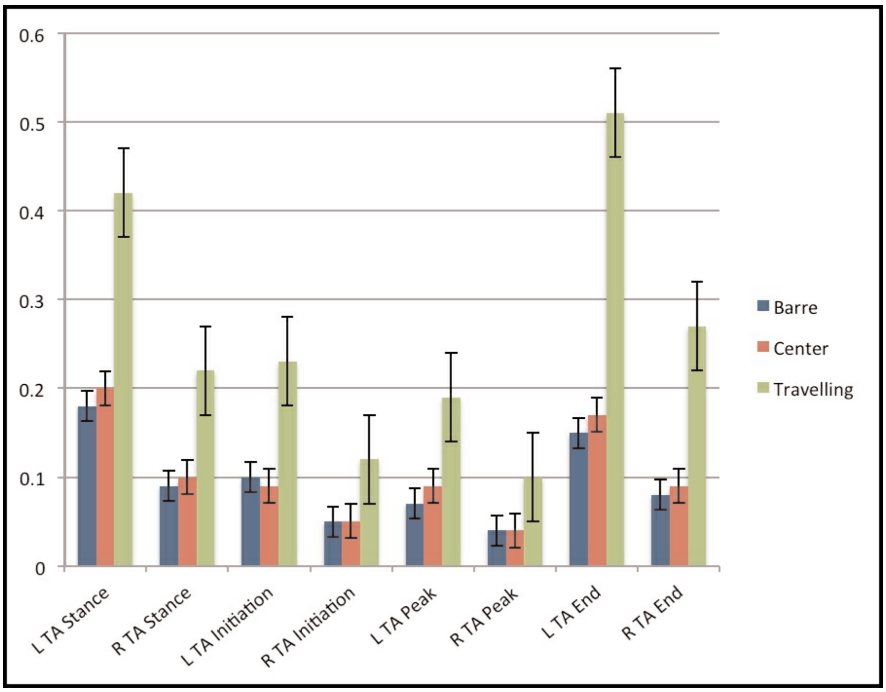

FIGURE 8. Tibialis anterior (left and right) by condition by event

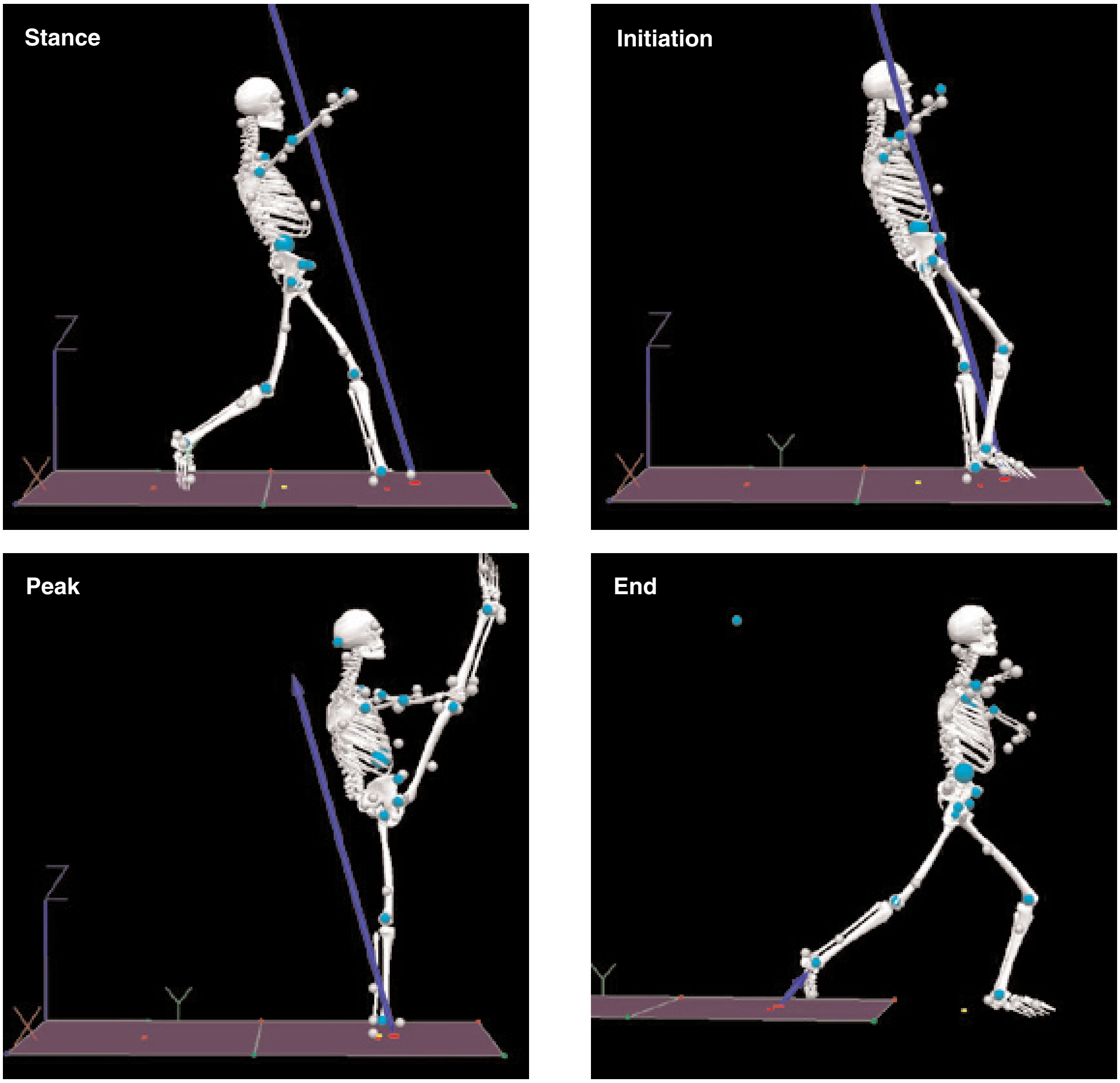

FIGURE 9. Four events for *grand battement devant* in the traveling condition

Overview of Each Muscle for all Conditions

While the ABS demonstrated changes primarily in the traveling condition of the initiation and end events, it was surprising to see how little change there was across the three conditions for peak. One might think that at the peak of the *battement*, abdominals would increase activity to assist in stabilizing the trunk, but this was not the case. The ES appeared as an inverse image to the ABS, with more activity during traveling for stance and peak, but not for initiation and end (see Figures 1 and 3). It may be that the ABS and ES act in a cooperative manner over the four events, with ABS increasing activation across conditions for initiation and end, while ES has the opposite pattern, increasing activation across conditions, for stance and peak. Dance educators may place such a high emphasis on abdominal use in dance training that the motor control of multiple trunk muscles is overlooked in cuing and instruction.

The other surprising result was the lack of GM activity on the right (gesture) leg throughout the movement, with values staying below 20% of maximum for all events and below 10% for peak (see Figure 5). While some have theorized that the GM needs to shut off at peak to accommodate full hip flexion, others have suggested that it remains active for external rotation. In the study by Bronner and Ojofeitimi,[13] external rotation diminished at the peak of *grand battement devant* in elite dancers. In this study, the gesture leg GM was quiet at peak and, in fact, was at low levels throughout the movement. On the standing (left) side, however, we see more GM activity, particularly in traveling at initiation and end. The left GM demonstrated its highest activity at the *barre* and center in stance, before any movement initiation began. Similarly, the right (gesture) leg HAM was fairly quiet throughout the movement (below 15%), with highest levels in stance; on the left (standing) leg, activity was greater than the right HAM in all events and also highest in stance (see Figure 6).

The QA demonstrated low levels of activity in stance during the traveling condition (the moment of shifting weight onto the left leg in preparation of the *battement*), a

TABLE 5. Results (*p*-values) of Analysis of Muscle × Training Level

Muscle	Beginner to Intermediate	Intermediate to Advanced	Beginner to Advanced
Abdominals	0.3	0.03	0.12
Abductor hallucis	<0.01	0.01	<0.01
Erector spinae	0.01	0.01	0.07
Gastrocnemius	0.2	0.01	0.01
Gluteus maximus	0.98	0.09	0.26
Hamstrings	0.35	0.07	0.77
Quadriceps	0.63	0.05	0.02
Tibialis anterior	0.34	0.04	0.11

significant increase at Initiation (as the gesture leg passes the standing leg and the standing leg begins to straighten), a drop back down to stance levels at peak, and another rise with traveling at end (the moment of shift onto the new supporting leg) (see Figure 7). It is probable that the high activity of the QA at Initiation relates to stabilization on the standing leg, which is changing from *plié* to straight in the traveling condition. Surprisingly, at *barre* and center, the greatest QA activity for both legs was in the stance event, much higher than at any other event, and in comparison to other muscles. One might wonder why dancers are using such high levels of QA activity (40-60%) just standing in first position. It may be that dancers are being cued to overexert in the quadriceps muscles in standing postures, even though much lower levels of activation are needed for dynamic movement, as shown in Figure 7.

We had anticipated greater difference in the TA between *barre* and center, due to its importance in postural reflexes,[11] but this was not the case (see Figure 8). As mentioned previously, the two muscles that consistently demonstrated differences for almost all conditions and events were the AH and the GA (see Figures 2 and 4). As noted earlier, the balancing mechanism described by Cordo and Nashner[11] starts with activation of the TA and GA at the moment of loss of equilibrium in natural (parallel) stance. It may be the case that with external rotation, the TA moves to a lateral (frontal plane) position with respect to the movement, and the AH takes over some of the anterior postural adjustment. While dancers do strength work for other small muscles of the foot, the AH might be a muscle of consideration for further training of the deep intrinsic muscles of the foot.

Training Levels: Level × Side × Muscle

First, it should be noted that the pattern of change for all muscles from *barre* to center to traveling is similar for all three levels of training in this study. When a muscle increased or decreased activation from *barre* to center, or center to traveling, it did so for all three training levels. What is different between the three training levels is amplitude, or percentage of maximum used. For almost all muscles, for all events, the intermediate dancers used the least percentage of maximum, the advanced dancers used the highest percentage of maximum, and the beginners were in between. It may be that dancers go through a transitional phase in which they diminish muscle use while trying to find more efficient motor patterns and eliminate unnecessary tension, and then once they are organized, they begin to work at higher levels of muscle activation again. It would require a longitudinal study to answer this question fully. Exceptions to this pattern were right (gesture) ABS, AH, and right (gesture) GM in which the beginners use a higher percentage than the advanced dancers; the ES and HAM, for which beginners and advanced dancers are almost identical; and left QA, for which beginners and intermediate dancers are almost identical. It may be that the beginners use a higher percentage of maximum for right ABS and right GM due to attention to the gesture leg as opposed to the standing leg, whereas advanced dancers may put more focus on the supporting leg to achieve the task, perhaps due to cueing from teachers as well as enhanced balance. Further research may shed some light on this hypothesis.

RELEVANCE

It is crucial that dancers develop appropriate motor strategies and muscle activation levels as part of their dance training to ensure coordinated movement. This could potentially reduce injury incidence due to factors such as overuse and fatigue[37,38] and loss of balance and control.[39] The results of this study and previous research suggest that dance classes devoting an inordinate amount of time to *barre* work may not develop appropriate strategies for unsupported and traveling movement.[2,7,10] In particular, this study indicates that it is the traveling condition that requires muscle activation levels and organization that are unique in dance practice. By overemphasizing the *barre* and center portions of training, dancers may be disadvantaged in terms of the skills and strategies necessary for elite performance. It is recommended that dance training and injury rehabilitation consider the importance of allocating sufficient time to each of the three conditions, *barre*, center, and traveling, to ensure development of varied and appropriate motor strategies for weight transfer and muscle activation in dance practice.

CONCLUSION

This is the first known study in the published literature to consider dance movement traveling and to compare it to *barre* and center practice. This study provides useful information about important differences in muscle use between *barre*, center, and traveling conditions and it provides insights into aspects of muscle activation within each condition. Additionally, it suggests that overall, intermediate dancers use the lowest percentages of maximum muscle activation for all conditions during the *grand battement devant*, with advanced dancers using the highest percentages of maximum. Previous studies have demonstrated mixed results concerning muscle use in advanced and novice dancers, and this study provides additional information about training level differences. It is clear from this study that muscle activation levels differ between *barre*, center, and traveling for the *grand battement*, and each condition requires sufficient attention during training to develop the appropriate motor strategies. Educators are encouraged to examine class structure to ensure development of a variety of motor strategies and muscle activation levels for dance practice.

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