Development of a Portable Anchored Dynamometer for Collection of Maximal Voluntary Isometric Contractions in Biomechanics Research on Dancers

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Surface electromyography (sEMG) has been used in dance medicine research since the 1970s, but normalization procedures are not consistently employed in the field. The purpose of this project was to develop a portable anchored dynamometer (PAD) specifically for dance-related research. Due to the limited studies in the dance research literature using normalization procedures for sEMG data, a review of the procedures used in the exercise science literature was conducted. A portable anchored dynamometer was then developed and tested with dancers, using methods validated in previous literature. We collected sEMG maximum voluntary isometric contractions (MVIC, mV) from 10 female dancers (mean age 31.0 ± 15 yrs, mean height 163 ± 7.6 cm, mean weight 57.6 ± 6.9 kg, and 17.0 ± 13.9 yrs of training in ballet and/or modern dance) over three trials (5 sec each) for eight muscles bilaterally (quadriceps, tibialis anterior, abductor hallucis, gastrocnemius, hamstrings, gluteus maximus, erector spinae, and rectus abdominus). Consistency of data and feedback from dancers suggest that this dance-specific portable anchored dynamometer is effective for future sEMG studies in dance research. *Medical Problems of Performing Artists* 2011; 26(4):185–194.

Electromyography has been in use to study dancers' muscle activity since the late 1970s,[1] with researchers examining a broad range of dance movements including *pliés*,[2-6] *relevés*,[7-9] *degagés*,[10,11] *développés*,[12,13] *grand battement*,[1,14] forward stepping,[15,16] and elevation work.[17-19] In a recent review of literature, Krasnow et al.[20] stated that in the 21 dance research studies using surface electromyography (sEMG) that they considered, less than half utilized any method of data normalization in order to enable sEMG amplitude comparisons across subjects or over time. The studies that did not collect data for normalization only assessed onset times of muscle activation in a given single testing session and therefore did not require normalization procedures. The studies that collected normalization data used a variety of methods including average rectified values, manual resistance testing, and use of isokinetic equipment. To date, no dance research studies have used hand-held dynamometers or dynamometer anchoring systems.

While many research questions do not require the assessment of amplitudes, it is imperative to consider a method for the collection of sEMG normalization data to provide clearer insight into muscle activation patterns in dancers, a specialized subset of the physically active population. Therefore, the project was in two stages: (1) the first stage examined the existing exercise science literature using dynamometer sEMG collection procedures to determine the potential for this procedure for dance research; (2) the second stage aimed to develop a portable anchored dynamometer (PAD) that could be easily constructed and implemented for dance-specific EMG research, and to validate this system based on previous methodology in exercise science research and pilot studies with dancers.

STAGE 1: REVIEW OF LITERATURE

Dynamometers for sEMG Normalization

One preferred normalization procedure in sports and exercise science literature is the data collection of maximum voluntary contractions (MVCs) or maximum voluntary isometric contractions (MVICs), using a percentage of maximum values to compare subjects.[21-25] Burden[26] emphasized the importance of normalizing sEMG data if comparisons were made between different muscles and different individuals. In

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his review of the literature over the past 25 years, he assessed eight normalization methods and concluded the following:

1) sEMG data from MVCs and MVICs are equally reliable, and further, these values are as useful as using the dynamic maximum of the movement trial under investigation;
2) using either submaximal isometric values or maximal isometric values at an arbitrary joint angle in mid-range is acceptable, as both have good reliability;
3) evidence does not support the need to match the specific joint angles during MVIC collection or joint ranges during MVC collection to the movement trials in order to have reliable comparison data;
4) dynamic MVCs should be used only if it can be determined that the task being used for the MVC collection can elicit maximal contractions in all of the muscles under investigation; and
5) in conclusion, use of sEMG data from an MIVC is the recommended method as a normalization reference value.

Standardized Equipment

The traditional method of collecting MVIC data has been the use of standardized equipment designed for muscle testing. However, there are pragmatic problems with the use of equipment, such as the Biodex and Kin Com systems for MVC and MVIC data collection, in dance research. First, the available equipment does not allow for much flexibility in terms of body positioning for data collection on a given muscle. Second, if multiple electrodes are placed on the body, it can be difficult to place the subject on the equipment in various positions without disrupting some of the electrode placements. Third, for dance researchers, access to this equipment, particularly in a dance-suitable space, can prove challenging. Finally, dancers often find using this type of equipment so atypical of their normal training process that it is questionable if they are able to elicit maximal or reliable levels of muscle activation.[27]

Hand-held Dynamometer

In seeking alternatives to the standardized equipment, researchers in sport and exercise science have explored the use of devices known as hand-held dynamometers (HHD).[28–34] The dynamometer measures the muscle force that a subject can elicit, while a trained tester provides resistance so that the subject can achieve high levels of muscle contraction.

In an early study by Agre et al.,[28] the HHD was found to be reliable for upper extremity testing but not for lower extremity testing, due to the lack of stability of the tester. The variation coefficient of the methodology error (CV) was between 5.1% and 8.3% for all upper extremity muscle tests, which the authors considered acceptable reliability for clinical muscle strength testing, but the lower extremity values ranged from 11.3% to 17.8%, resulting in poor reliability. Andrews et al.[29] assessed an HHD device, examining eight upper extremity and five lower extremity movements, and used the results to determine normative values for populations 50 to 79 years old. The researchers concluded that while the testing methodology is reliable, the training, experience, and strength of the tester are important factors.

Wikholm and Bohannon[34] had three testers measure two upper and three lower extremity muscles for 27 subjects. They selected three testers with measurably different strength levels and muscles with different maximum force productions. They found that there was considerable variability in results. As the tested muscles increased in force production, the interrater intra-class coefficients (ICCs) decreased in magnitude (0.932 to 0.226). Similar results were seen for intrarater/intrasession ICCs. They concluded that these results were most likely due to differences in individual examiner's strength levels and the subsequent resistance they were able to offer to the subjects during testing.

Bohannon[30] used one tester to assess 6 upper extremity and 4 lower extremity muscles for 106 men and 125 women and confirmed that reliable measurements could be obtained using an HHD. He observed, however, that the tester must be strong enough to provide sufficient resistance to the subject's efforts, and the technique must be clearly defined, systematic, and consistent. Kelln et al.[32] tested 11 lower extremity muscles of 20 subjects, using three testers on 2 separate days, with the following results: intratester ICCs ranged between 0.77 to 0.97 with standard error of measurements (SEM) range of 0.01 to 0.44 kg. Mean intertester ICC range was 0.65 to 0.87 with SEM range of 0.11 to 1.05 kg. Mean intersession ICC range was 0.62 to 0.92 with SEM range of 0.01 to 0.83 kg. Similar to Bohannon,[30] Kelln et al. suggested that the limitation of such a hand-held device was in attempting to test movements in which the subject could overpower the tester.

Bohannon[31] reviewed 13 published articles in the literature using HHDs to determine the responsiveness of the testing device over time. Using effect size as the measure of responsiveness, he concluded that HHD could detect changes in limb strength due to interventions. Thorborg et al.[33] used the HHD to assess hip abduction, hip adduction, hip external rotation, hip internal rotation, hip flexion, and hip extension, all of which would be highly applicable to dance research. In test-retest trials, they examined measurement variability and found highly reliable results, with measurement variation between 3% and 12% for the various muscles between sessions. It should be noted that the tester did enthusiastic cueing during these data collection sessions, which was seen as an important component in obtaining reliable results.

Portable Anchored Dynamometers

In order to mitigate the problem of the subject overpowering the tester, and to provide more consistent positioning of the resistance, researchers have designed portable anchoring systems, using solid apparatus and belts as the resistance modality. For example, Kramer, Vaz, and Vandervoort[35] used a combination of HHD and belt resistance, and they found that this method required less strength on the part of the examiner and greater stabilization of the subject and was preferred by the majority of subjects. Similarly, Bolgla and Uhl[23] compared the reliability of three normalization methods for testing hip abductor strength—maximum voluntary isometric contraction (MVIC), mean dynamic activity, and peak dynamic activity—all using a table and resistance belts. The researchers concluded that this MVIC collection method provided the highest level of reliability. They further commented that factors that impacted reliability were body positioning, verbal encouragement, and task familiarization.

Nadler et al.[36] designed a portable dynamometer anchoring station that measured the strength of the hip extensors and abductors. Ten subjects were tested twice, 2 weeks apart, with the evaluators blinded. They computed the ICCs for both maximum (ICC 1,1) and average (ICC 1,3) strength, which ranged from 0.94 to 0.98. The average CV (coefficients of variation) for maximal abduction strength was 4.77% and for average abduction strength was 4%. Average CV for maximal extension strength was 8.06% and for average extension strength was 7.83%. Thus they concluded that this method of collection was highly reliable and particularly useful for testing powerful muscles that might not be easily assessed using an HHD device.

Finally, Scott et al.[37] compared the inter- and intra-rater reliability of a portable anchored dynamometer (PAD) to an HHD, assessing hip abduction, extension, and flexion, using two testers with a 1-hour break between sessions for the subject. Interrater ICCs of average peak strength ranged from 0.84 to 0.92 (hip flexors), 0.69 to 0.88 (hip abductors), and 0.56 to 0.80 (hip extensors). Intra-rater ICCs ranged from 0.59 to 0.89 for tester A and from 0.72 to 0.89 for tester B using the PAD, and from 0.67 to 0.81 for the HHD across muscle groups. The PAD was highly reliable for hip flexion and abduction, whereas the HHD was more reliable for hip extension. They concluded that both systems yielded reliable test results.

Summary of Literature Review

In summarizing the literature about sEMG normalization procedures, MVICs are highly reliable for normalization of sEMG data collected during movement trials.[23,26] Standardized equipment is problematic for dancers,[27] but dynamometers can reliably determine muscle strength for the purposes of muscle testing,[28,29,32,34] and the limitations due to tester strength and variability can be overcome using PADs.[23,35,36] Other recommendations include familiarity with procedures and enthusiastic cueing.[33]

STAGE 2: NEED FOR DANCE-SPECIFIC PAD

To our knowledge, no PAD has been devised for dance medicine and science research. The anchoring systems presented in the sports and exercise science literature do not always replicate the typical movement patterns during dance movement. For example, in sports and exercise science, the PADs typically test the gluteus maximus in the seated position with the subject pressing downward; however dancers are more familiar with use of this muscle in movements such as the *arabesque*, where the dancer is in a one-legged stance with the free leg behind the body in hip and knee extension. Therefore, we decided to address this absence of a dance-specific dynamometer system by designing a customized PAD.

The second stage of the project was the development of a portable anchored dynamometer (PAD) that can be easily constructed and implemented for dance-specific EMG research and the validation of this system based on previous methodology in exercise science research and pilot studies with dancers. The three steps were:

1) First, we chose to adapt a previously reported PAD, by modifying the body positioning, to create a similarity to dance movements.
2) Second, we replicated procedures that are reported to result in reliable results in previous literature.
3) Third, we tested this PAD on dancers, asking them for subjective feedback on comfort and effort levels when using this apparatus.

METHODOLOGY

Subjects

Ten trained female dancers (mean age 31.0 ± 15 yrs, mean height 163 ± 7.6 cm, mean weight 57.6 ± 6.9 kg, and 17.0 ± 13.9 yrs of training in ballet and/or modern dance) participated in this study. Subjects were only included if they had no injuries that might impede successful completion of the tasks. Dancers were volunteers from local colleges, universities, professional dance schools, and dance studios and were recruited through announcements in dance classes, listings in dance newsletters, and emails. Dancers were volunteers from local colleges, universities, professional dance schools, and dance studios and were recruited through announcements in dance classes, listings in dance newsletters, and emails. Dancers were intentionally selected with a broad range of demographics, due to the potential variable subject pool for future research. All test procedures were described and explained to the subjects prior to preparation for testing and data collection, whereupon they signed an informed consent form. All procedures were approved by the university institutional review board.

General Approach

The method first proposed by Nadler et al.[36] was modified for this study. The PAD incorporates several of the positive variables described in previous research,[23,31,33,35,36] including a combination of a table and resistance belts for stability, body positioning that is familiar to the dancer, practice trials, and enthusiastic cueing during collections.

The Instrument

The apparatus components can be seen in Figure 1. The system consisted of the following equipment: (1) a padded treatment table; (2) a lightly padded removable back support that was mounted on the table for the seated work and adjusted so that the subject's knees reached the end of the table in the seated position; (3) an adjustable, padded board

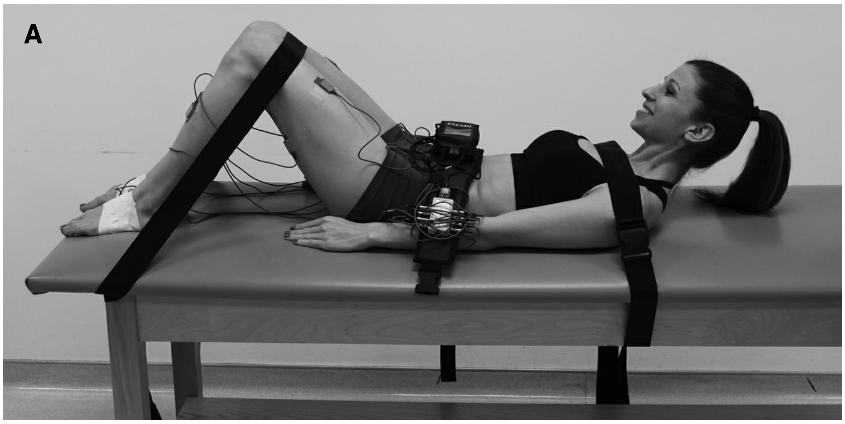

FIGURE 1. Components of the PAD, showing positioning of the dancer and electrode placement during testing of the eight muscles: testing of the abdominals (*panel A*) is shown here, and others (*panels B–H*) are on the facing page.

with clamps (Irwin® Quick-Grip® Clamps; Irwin Tools, Huntersville, NC, www.irwin.com) that can be attached onto the table legs and adjusted to adapt to the height and leg length of the subject; (4) straps for stabilizing the subject for the MVIC tests; and (5) a 6-inch diameter foam roller to assist with knee flexion in some of the electrode placements and some of the MVIC data collection.

Electrode Placement

All subjects wore sports bras and spandex shorts during the testing and completed all trials in bare feet. Surface electrodes (DE 2.3, Myomonitor Single Differential Ag electrodes, skin contact size 10 × 1 mm, center-to-center distance of 10 mm) (Delsys Inc., Boston, MA; www.delsys.com) were applied over the skin after it was prepped with alcohol. Electrodes 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), hamstrings (HA), gluteus maximus (GM), erector spinae (ES), and
Standing: rectus abdominus (AB).

This order was selected to require minimal movement during the electrode placements, so that electrodes would not be disturbed.

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 25 to 350 m, preamplifier gain 1000 V/V with a frequency bandwidth of 20 to 450 Hz, a common mode rejection ratio of 92 dB_{min} 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, and absence of crosstalk was confirmed.

Data Collection Protocol

MVICs were collected in the order listed under Testing Protocol and Collection Order (see below). Note that data for AB and ES were collected bilaterally, i.e., right and left sides were recorded at the same time. Data for AH, GM, QA, HA, and TA were collected unilaterally, but alternating right and left, always starting with the right side for consistency. GA MVIC data were collected with all trials on the right side, then all trials on the left side, due to the complexity of moving the stabilizing straps. Joint angles for muscle testing were determined as per other previous studies in the literature using either HHD or PAD.[30,34] Only one muscle (AH) required an investigator tester to provide manual resistance. Due to the small force provided by the AH, the possibility of a subject overpowering the investigator was ruled out. Still, to reduce inter-tester variability, the same investigator provided the resistance for all subjects.

For supine position data collection, the Myomonitor belt was held off the subject's body; for prone position data collection, the wireless transmitter was not in the belt, but the belt was attached to the subject; for seated position data collection, the belt was again held just off the subject's body.

Testing Protocol and Collection Order

After electrode placement, the subject was given 15 minutes for a general warm-up. After warm-up, the investigator examined the electrodes to ensure that none had moved or dislodged. Prior to MVIC collection for each muscle, the subject was given practice trials until she informed the investigator that she was familiar with the procedure. After the practice trials, the subject performed three MVICs using the "make test" for each muscle,[23,29,30] with 30-sec rest between collections. For the "make test," subjects generated maximum muscle force over a 2-sec period and held the maximum contraction for a 5-sec period. The principal investigator provided enthusiastic verbal encouragement during all data collections.[33] The specific positioning for

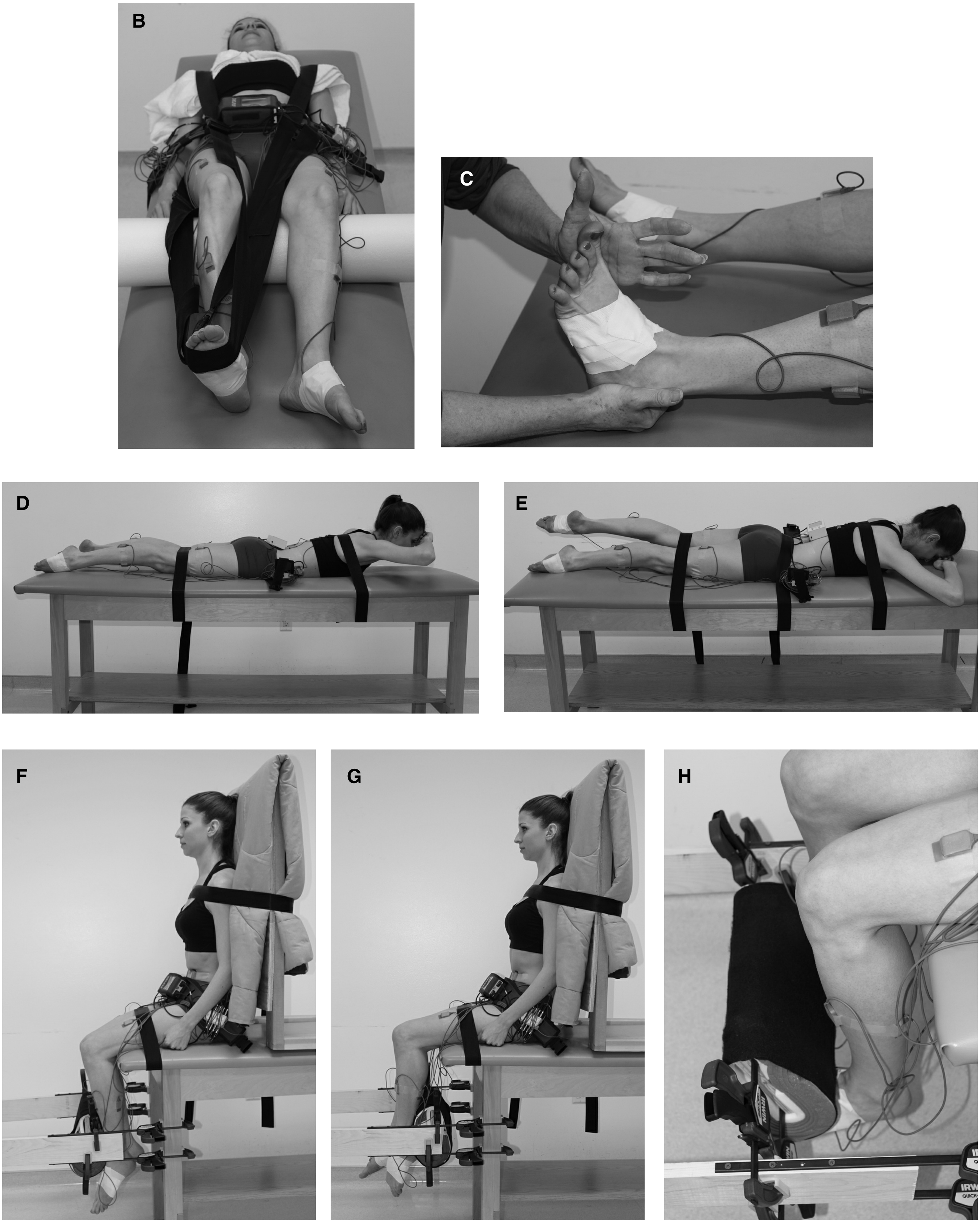

FIGURE 1 (cont.)**.** Components of the PAD, showing positioning of the dancer and electrode placement during muscle testing; **B**, right gastrocnemius; **C**, left abductor hallucis; **D**, erector spinae; **E**, left gluteus maximus; **F**, left quadriceps; **G**, left hamstrings; **H**, left tibialis anterior.

each muscle can be generally seen in Figure 1 and is described in detail below:

Supine

1. **Spine flexion, MVIC for abdominals (AB):** The subject was supine on the table in a hook lying position, with the toes at the edge of the table's end (hips flexed to 45° degrees and knees flexed to 90°). Arms were placed at the sides of the body, and the strap crossed the chest just below both clavicles and over the humeral heads. A second strap was placed over the distal femurs, just superior to the patellae, and attached to the end of the table, parallel to the tibias. The subject attempted to flex the spine (i.e., to curl the shoulders and knees together, while performing a posterior pelvic tilt). See Figure 1A.
2. **Ankle plantar flexion, MVIC for gastrocnemius (GA)**: The subject was supine on the table. Two straps were placed around the distal metatarsal heads, and each strap was then placed over the acromioclavicular joint of each shoulder. Straps were initially tightened with the ankle in dorsiflexion so that the slack was taken up during the muscle contraction, and the ankle was at 90° for the MVIC. A 6-inch foam roller was placed under the knee, creating approximately 30° of knee flexion. The subject pressed against the straps, attempting to point the foot (i.e., plantar flex the ankle). Subjects were allowed to wear ballet slippers if they so chose. See Figure 1B.
3. **Big toe (hallux) abduction, MVIC for abductor hallucis (AH):** The subject was supine on the table with a small pillow or folded towel under the head, and a foam roller under the knees for support. The subject began in full active dorsiflexion, spread the toes, and then abducted the hallux against the hand of the investigator. The investigator stabilized the subject's heel with the other hand. (Note that some inversion may also occur and is acceptable.) See Figure 1C.

Prone

4. **Spine extension, MVIC for erector spinae (ES):** The subject was prone on the table. One strap was placed over the scapulae and thoracic spine at the level of the axilla. A second strap was placed at the posterior distal femurs, superior to the knee joints. The arms were folded, hands placed under the forehead, elbows out to the side. The subject attempted to extend the spine (lift the upper torso) off the table. The arms lifted off the table, while the hands remained in contact with the forehead. Dancers were instructed to raise their torso off of the table with the greatest effort possible, and they could use the lower extremities as they saw fit. See Figure 1D.
5. **Hip extension, MVIC for gluteus maximus (GM):** The subject was prone on the table. One strap was placed over the scapulae and thoracic spine at the level of the axilla. A second strap was placed at the posterior distal femurs, superior to the knee joints. A third strap was placed just above the posterior superior iliac spines (PSISs). The arms were folded, hands placed under the forehead, elbows out to the side. The subject extended one hip with maximal effort. See Figure 1E.

Seated

6. **Knee extension—MVIC for quadriceps (QA):** The subject sat off the end of the table with hips and knees flexed to approximately 90°. The upper thighs were stabilized to the table by a strap placed at the mid-femurs. The trunk was stabilized to the back support by a strap across the upper trunk just below the axilla, arms relaxed at the sides of the body. The anchoring system was attached by clamps to the table legs at level of subject's lower legs, anterior to the tibia. The subject extended one knee with maximal effort. See Figure 1F.
7. **Knee flexion, MVIC for hamstring (HA):** The subject sat off the end of the table with hips and knees flexed to approximately 90°. The upper thighs were stabilized to the table by a strap placed at the mid-femurs. The trunk was stabilized to the back support by a strap across the upper trunk just below the axilla, arms relaxed at the sides of the body. The anchoring system was attached by clamps to the table legs at the level of the subject's lower legs, posterior to the tibia. The subject flexed one knee with maximal effort. See Figure 1G.
8. **Ankle dorsiflexion, MVIC for tibialis anterior (TA):** The subject sat off the end of the table with hips and knees flexed to approximately 90°. The upper thighs were stabilized to the table by a strap placed at the mid-femurs. The trunk was stabilized to the back support by a strap across the upper trunk just below the axilla, arms relaxed at the sides of the body. The anchoring system was attached by clamps to the table legs at the level of the subject's foot, anterior to the foot, resting on the metatarsals. The subject began with the ankle in approximately 35° of plantar flexion and dorsiflexed the ankle with maximal effort, which caused the foot to push against the anchoring system with the ankle at 90°. See Figure 1H.

Data Processing

All sEMG data were processed using Visual 3D (C-Motion Inc. Germantown, MD). The sEMG signals were first processed with a band pass filter from 10 to 450 Hz, using a fourth-order, zero-lag Butterworth filter. The sEMG signals for the MVICs were then smoothed using a 99-ms-wide RMS time window to obtain steady-state results. Three trials for each muscle were ensemble averaged to obtain one composite representative trial for each muscle using a customized pipeline.

RESULTS

The purpose of developing the PAD described in this article was to design a normalization procedure for sEMG data collection for dance-related research. In this context, the system needed to be portable for use in dance spaces, to be modified in terms of body positioning for dancers, and to provide consistent and reliable results.

All subjects reported that the PAD was comfortable yet challenging. Subjects also indicated that they provided their maximal effort and were pleased that the testing was performed using dance-specific positions. Figure 2 represents a single representative MVIC data collection trial for the left gastrocnemius of one exemplar subject. The figure exhibits raw data for all eight muscles on the left side during this trial. The gastrocnemius graph in Figure 2 clearly demonstrates a specific onset and activity above baseline for this muscle. Other active muscles in this trial include abdominals, erector spinae, and hamstrings. This muscle activation pattern is what would be expected for a gastrocnemius trial, with the

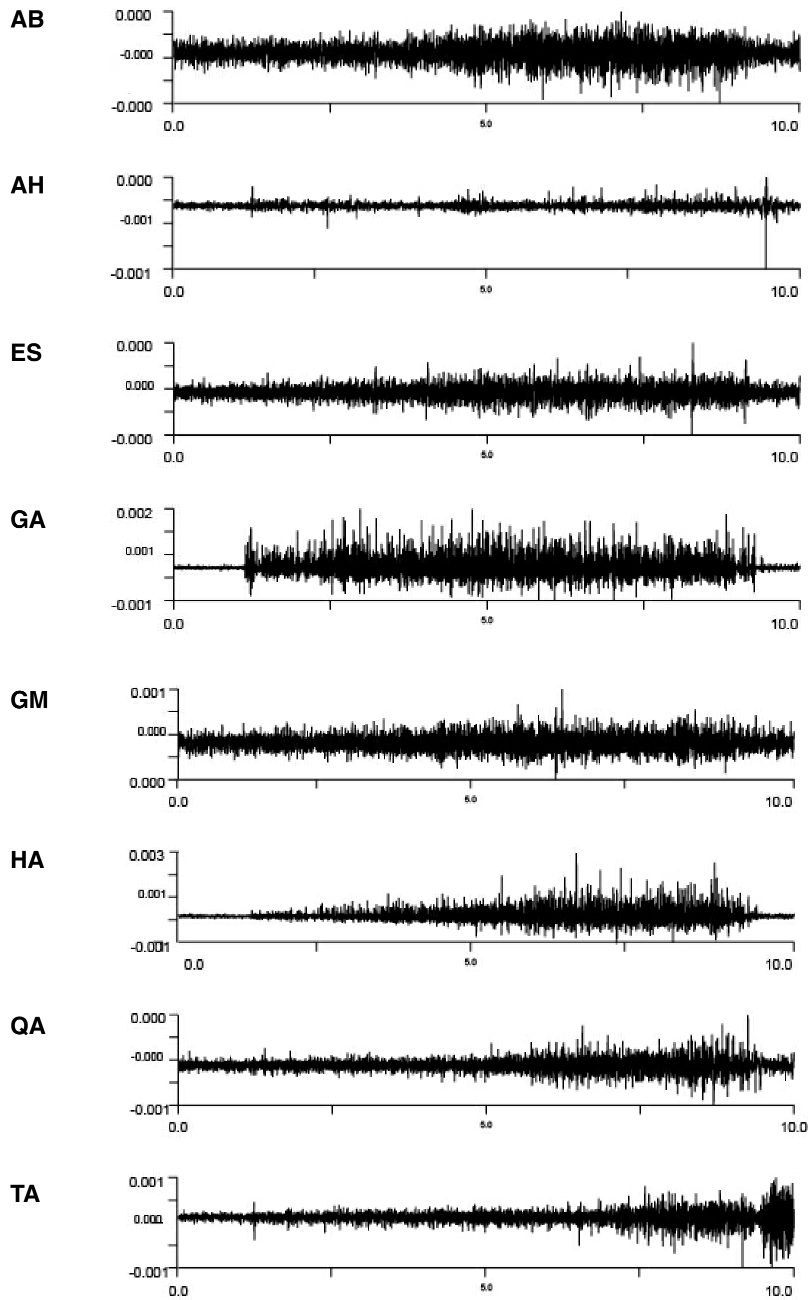

FIGURE 2. Left gastrocnemius trial: Raw data from sEMG recordings for AB (abdominals), AH (abductor hallucis), ES (erector spinae), GA (gastrocnemius), GM (gluteus maximus), HA (hamstrings), QA (quadriceps), and TA (tibialis anterior) muscles. X-axis is in seconds, Y-axis is in millivolts.

muscles contributing to trunk stabilization and knee flexion active during this MVIC data collection.

Figure 3 represents the conversion of raw data to filtered data for four of the muscles seen in Figure 2 during the MVIC data collection for the left gastrocnemius. It can be seen that the gastrocnemius and hamstrings are both active in this trial, whereas the tibialis anterior and abductor hallucis are unchanged relative to baseline. These results are consistent with what would be expected in dance trials for the gastrocnemius muscle. These graphs are representative of the graphs for the muscles tested in these pilot studies, with clear bursts of activation for the target muscle, supporting activity in muscles contributing to stabilization, and little or no activity in remaining muscles.

Figure 4 represents all three MVIC trials for the left gastrocnemius for the same subject, with the bolded line being the average of the three trials. Again, this graph is representative of the three-trial and average graphs for the tested muscles in the pilot study. The individual trial lines and the bolded average line are similar to results found in previous

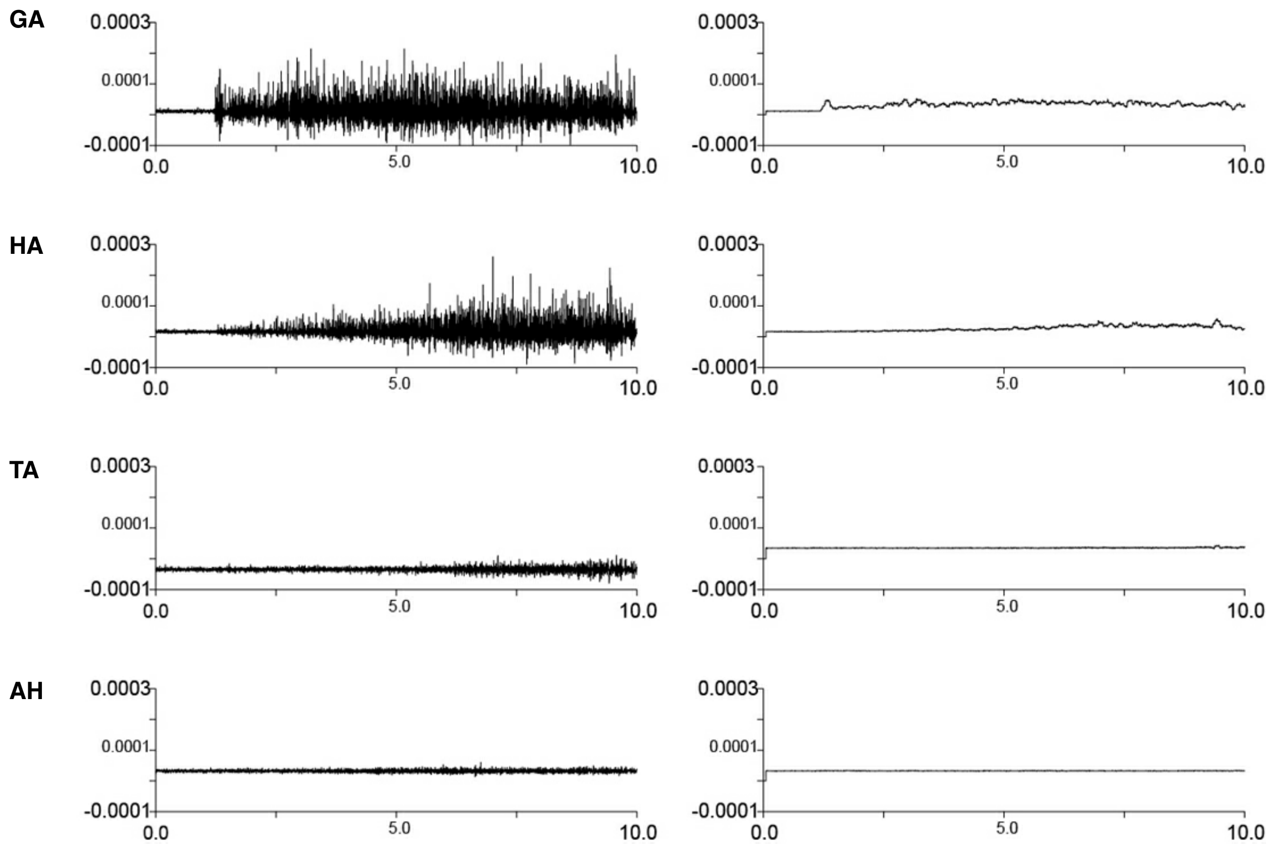

FIGURE 3. Left gastrocnemius trial: Raw (*left*) and filtered (*right*) data from sEMG recordings for GA (gastrocnemius), HA (hamstrings), TA (tibialis anterior), and AH (abductor hallucis). X-axis is in seconds, Y-axis is in millivolts.

literature. They demonstrate the general consistency of our PAD across the three trials, as well as within each trial. Although we did not do repeat trials in a second testing session due to time constraints, we were satisfied that these results suggest consistency with this procedure.

DISCUSSION

This project was undertaken in two stages: (1) The first stage was to examine the existing exercise science literature using dynamometer sEMG collection procedures to determine the potential for this procedure for dance research. (2) The second stage was the development of a portable anchored dynamometer (PAD) that can be easily constructed and implemented for dance-specific EMG research, and the validation of this system based on previous methodology in exercise science research and pilot studies with dancers. The lack of normalization procedures in the dance science literature caused us to examine the exercise science research for background in developing our system.

While the exercise science background provided methods that have been tested and found reliable and consistent, they also presented barriers to use with dancers. One constraint was the issue of equipment that would be too unwieldy to move easily in and out of dance spaces. If testing is to be done on dance movement, the space must be appropriate for dance in terms of floor surface, amount of space, and availability of dance apparatus such as barres and sound systems. Therefore, we needed to design a PAD that was easy to assemble quickly and lightweight. A second issue was the need to modify body positioning that would be familiar to dancers, allowing them to achieve high levels of muscle activation in a known context.

Although we sought volunteers from a wide range of dance schools and studios and university dance programs, only one male volunteered for the study. Therefore, we decided to conduct the investigation on female volunteers only. First, using only one male might be potentially problematic, if he were atypical, and second, the development of the PAD is for use in a larger study that will be conducted exclusively on female dancers. We would recommend testing the PAD on male subjects at a future time, so that it has broader applications for a more general dance population. Although there were only 10 subjects in this investigation, small subject pools are not uncommon in research on dynamometers and PADs.[23,28,36] Given the consistency of the results and feedback from the subjects, we are confident that the system is reliable for an adult female dance population, and larger numbers are not necessary to validate these results.

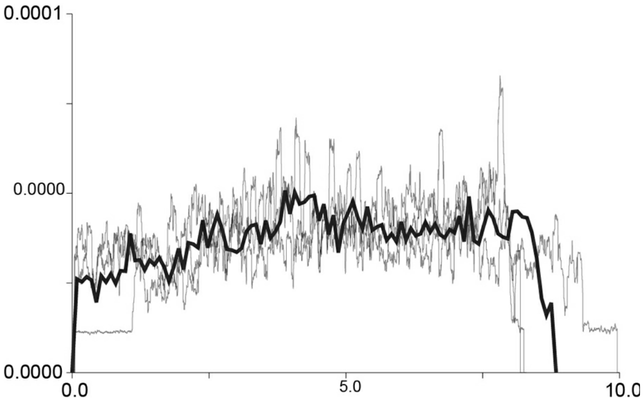

FIGURE 4. Left gastrocnemius trial: three MVIC trials and ensemble graph. This graph shows the composite data of the three trials, with the bold line showing the average. X-axis is in seconds, Y-axis is in millivolts.

In developing the PAD, we incorporated methods described and found reliable in the literature, but also considered the weight and assembly ease of the apparatus and dancers' comments about comfort and best positioning for eliciting maximal effort. The PAD described in this article can be stored in a closet space and assembled in 5 minutes. It can be moved easily by two people of moderate strength levels. The verbal feedback from the subjects suggested that they felt comfortable in the positions described above, and they were confident that they were contributing their best efforts. Additionally, Figures 2 to 4 depicted above are typical of the data collection from the 10 subjects for all muscles tested and suggest that the dancers were capable of eliciting consistent and maximal efforts in the positions selected through this entire testing of the PAD. The results and the dancers' responses support the use of this apparatus for MVIC data collection on dancers.

CONCLUSION

sEMG is a useful tool for dance medicine and science research, and as the technology improves, it will be increasingly beneficial in the understanding of dance biomechanics. It is essential that dance medicine and science researchers begin to understand methods of normalization of sEMG data across subjects and across time, so that researchers can conduct studies across subjects, days, groups, and locations. The dance-specific PAD described in this article builds upon methods described in previous literature and provides a reasonably inexpensive, practical way to collect MVICs in this population. We acknowledge that the reliability of this system is currently presumed for single-session, single-tester studies. Thus, we recommend that future testing of this PAD include multiple-session, multiple-tester testing. The PAD developed, modified for dancers, and tested in this study provides a standardized procedure that dance researchers can use for future research involving the use of sEMG.

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