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Reliability of a Barre-Mounted Dynamometer-Stabilizing Device in Measuring Dance-Specific Muscle Performance

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Comments

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The Reliability of a Barre-Mounted Dynamometer Stabilizing Device in Measuring Dance Specific Muscle Performance

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ABSTRACT

Background: Handheld dynamometry (HHD) is considered an efficient, effective, and portable means of objectively measuring lower extremity strength, however, it has yet to be studied specific to dance-relevant muscle performance. Furthermore, dynamometry is often criticized for variability in results based on tester strength and sex. Use of an external stabilizing device has been suggested to minimize differences in outcomes between male and female testers by reducing variability associated with tester strength limitations. Therefore, this study used a barre-mounted, portable dynamometer stabilizing device to improve consistency of results among different testers for assessing hip and lower extremity muscle performance in dance-relevant positions.

Objective: To assess the intra and inter-rater reliability of a barre-mounted dynamometer stabilizing device in measuring muscle performance in common dance maneuvers.

Study Design: Prospective Correlation Study

Level of Evidence: III

Methods: The primary investigator and a second tester assessed muscle performance of three common dance maneuvers: développé en avant, à la secondé, and arabesque, on 11 pre-professional and professional dancers on two separate occasions to establish intra- and inter-rater reliability of the barre-mounted dynamometer stabilizing device.

Results: Intra-rater reliability was moderate to high, and inter-rater reliability of the device was excellent, with Intra Class Correlation Coefficient values ranging from 0.527-0.851 and 0.834-0.953, respectively, for all positions. These results should be interpreted with caution, however, as these correlations are limited to two testers.

Conclusions: The barre-mounted stabilizing device shows promise in mitigating tester strength or fatigue in assessing the muscle performance of dancers. Initial assessment of the device suggests further study may be indicated to improve generalizability to

applications of larger scale muscle performance screening and assessment in dancers. or other athletic populations who engage in movements that require extensive hip range of motion and multi-joint stability.

Clinical Relevance: Using a portable, barre-mounted stabilizing device in assessing multi-joint lower extremity muscle performance in dancers improves consistency of testing results. Application of this testing device into wider scale screenings could assist in developing normative data for a population that is lacking. Broader applications to the upper extremity and other populations are possible.

KEY WORDS: Hip joint/*physiology, muscle strength dynamometer/*statistics & numerical data, dancing*

INTRODUCTION

The role of hip strength in various pain syndromes, impairments and athletic performance is extensively studied;[1-4] however, the hip strength demands necessary for dancing at a professional or elite level remain unclear. The reported overall lifetime injury incidence of dancers ranges between 42 to 97 percent.[5-11]Seemingly under-reported during a dancer's career, retired ballet dancers are 2.9 times more likely to report hip pain than non-dancers.[12, 13] Hip musculature provides dynamic stabilization and passive resistance to external forces. Axial loading combined with repetitive hip rotation without the prerequisite hip muscular performance is considered a potential precursor to hip pathology.[3] The repetitive nature of dance training, especially high frequency and volume external rotation, suggests the potential for injury to the capsulolabral and ligamentous structures of the hip joint associated with micro-instability is heightened.[14, 15] Appropriate hip muscle activation and strength are critical contributors to hip stability during dynamic movements of the lower extremity. At present, no study has quantified the strength required to sustain gesture limb position associated with the impressive aesthetics in dance.

Handheld dynamometry (HHD) is recognized as a reliable alternative to manual muscle testing for objective measurement of an individual's strength.[16-19] HHD provides a more cost-effective, efficient and portable means of assessing strength in a variety of clinical settings compared to isokinetic testing, the criterion standard for assessing muscle strength and performance.[20] Though more reliable and objective than traditional manual muscle testing, HHD is scrutinized for variability observed between testers of different sex and strength, as differences can exist in the tester's ability to stabilize the

HHD against repetitive force over time, or the tester's strength relative to the muscle group tested, particularly when assessing strong individuals (e.g. athletes).[17, 21] External stabilization of the HHD is suggested as a solution to reduce the influence of tester strength and the potential for systematic bias and large measurement variation across a study population.[1, 2, 20, 22] Nadler et al.[2] found an external anchoring device had excellent intra-rater reliability (ICC 0.94-0.98) in HHD measures of hip abduction and extension in collegiate athletes.

The purpose of this study was to assess the reliability of a barre-mounted dynamometer stabilizing device in evaluating muscle performance of dance-relevant positions. It was hypothesized that the stabilization device would be a reliable means of identifying mid-range muscle performance in dancers without hip pain. It was anticipated that test/re-test of muscle performance in dance-relevant positions with a barre-mounted stabilizing device would demonstrate consistency in results comparable to existing HHD reliability for both inter- and intra-rater reliability ($r \geq 0.80$; excellent).

METHODS

Study subjects

Eleven participants (3 males, 8 females) were recruited from the <BLINDED>. Ballet professional and pre-professional companies and schools via flyers, email and word of mouth communication. An *a prior* power analysis suggested 9 participants would be necessary to demonstrate 0.80 power, with 0.05 alpha and effect size of 0.70.[23] Participants were required to meet the following inclusion criteria: technical ability to hold développé en avant, a la secondé and arabesque at ≥ 90 degrees, currently dancing >20 hours per week, between 18-45 years of age, and available for testing on two, separate occasions. Both male and female dancers were included. Participants were excluded if they had an acute lower extremity or hip muscle injury, acute radicular lumbar pathology (current L2-S1 myotomal weakness, sensory disturbances in the lower extremity), or were unable to perform lower extremity weight bearing due to existing injury.

The study was approved by the <BLINDED> Institutional Review Board (# <BLINDED>). Informed consent was obtained from all participants prior to enrollment in the study and all rights were protected.

Procedures and Data Collection

The primary investigator and a second tester assessed 11 individuals in the dance-relevant positions described below. Both testers had over eight years of experience as physical therapists working with the dance population and underwent training to ensure testing was standardized.

On the initial visit, a pre-participation questionnaire, which included demographic information, dance training history and self-reported height/weight, was completed and informed consent was obtained. Participants completed a self-selected warm up as they would before a ballet technique class prior to testing. Tape was applied circumferentially around the right lower leg five centimeters above the superior aspect of the medial malleolus. Participants were instructed to establish contact of the tape to the dynamometer during testing to ensure consistency in force production lever arm across positions of relative hip flexion, abduction and extension. To avoid systematic bias, participants drew a card to determine which tester they began with. Test position order was randomized by card draw and recorded to allow for repeat testing on the second day of data collection. Test positions were performed on the right side only to measure muscle performance of:

- *Développé en avant (front):* Relative hip flexion and external rotation (participant behind stabilization device)
- *Développé a la secondé (side):* Relative hip abduction and external rotation (participant beside stabilization device)
- *Développé arabesque (back)*: Relative hip extension and external rotation (participant in front of stabilization device)

The primary investigator attached the stabilization device to a wall-anchored, wooden ballet barre. A Hoggan Scientific, LLC. microFET®2 digital handheld dynamometer muscle tester was attached to the disc of the stabilization device with Velcro squares and an elastic band (Figure 1). The device used a carbon fiber pole running at an oblique angle from the barre to the wall to maximize stabilization against vertically directed force. Stackable blocks were used to bring the subject's hip angle to 90° when necessary. The hip angle was assessed visually using the greater trochanter and lateral malleolus as reference points, and the standing leg as the vertical arm. Number of blocks were recorded to maintain consistency between the two days of data collection. The same studio and setup described above were completed on the second day of data collection.

Participants were instructed to use their normal degree of hip external rotation or turnout with full knee extension in each test position. Participants were allowed to stabilize with the hand closest to the barre during *développé en avant* and *arabesque* (Figures 2a and 2c), and rest both hands on the barre during *développé a la secondé*

(Figure 2b). Participants completed three trials of four to five seconds per test position. The testers used a scripted dialogue to minimize encouragement and maximize the force production: “Extend your leg in your normal turn out, and press into the dynamometer as hard as you can keeping your knee straight and hold, hold, hold, hold.” When necessary, the tester helped establish initial contact of the band of tape with the dynamometer.

An isometric “make” test was used to assess peak force production in développé en avant, a la secondé and arabesque of the right hip and lower extremity. A “make” test involves the subject exerting a maximal force against the dynamometer in a stable position, compared to a “break” test in which the examiner pushes the dynamometer against the subject’s limb until the subject’s maximal effort is overcome and the joint gives way.[24] Prior research has shown the “make” test produced more consistent magnitudes of force, contributing to higher observed reliability than “break” tests, where magnitudes were up to 1.3 times greater than “make” forces.[24, 25] The specific, dance-relevant positions selected are frequently executed and reflective of the characteristic tri-planar hip motion in dance.

Participants were allowed brief rest intervals of 30 to 60 seconds between test positions to allow for muscle recovery, and modification of block position to accommodate each new test position. Participants were given a break of at least 10 minutes between testers to allow for muscle recovery. Repeat testing using the above protocol occurred at least one week but no more than two weeks following initial testing. All 11 participants returned for the second day of testing.

Data Analysis

Data was analyzed using IBM SPSS Statistics for Macintosh, Version 23.0 (IBM Corp. Released 2015. Armonk, NY). Data was evaluated for outliers and skewness and found to be normal. Descriptive statistics were calculated for baseline demographic information. HHD data was evaluated to determine Intraclass Correlation Coefficient (ICC) and 95% Confidence Intervals (CI) using a 2-way mixed model with absolute agreement for intra-rater reliability, and a 2-way random effects model with absolute agreement for inter-rater reliability (ICC 2,k).[26] ICC values range from 0.0 to 1.0, with values closer to 1.0 representing stronger reliability.[27] For the purpose of this study, ICC values were classified as follows: low ≤0.49, moderate 0.50–0.69, high 0.70–0.89, and very high 0.90–1.00.[28] It should be noted that these values do not provide absolute standards; variability exists in reported levels of acceptance in the HHD literature. When interpreting ICC values, the clinician should be able to defend their classification of scoring based on the relative level of precision necessary in the observed measurements.[27]

The average of three trials per position was utilized for data analysis. The dynamometer measured force production in foot-pounds, which was converted to Newtons and normalized to participant weight (converted to Newtons by multiplying body weight in kilograms and the force of gravity) and height (meters) prior to data analysis. The formula used for normalization by weight and height was: $d/(bw*h) \times 100$ where d = dynamometry means, bw = body weight and h = height in meters. Additionally, standard error of measurement (SEM) was calculated with 95% Confidence Interval (CI) as:

$$SEM = SD\,[\sqrt{(1-r)}]$$

$$95\%\ CI = observed\ score \pm (1.96xSEM)$$

where SD = standard deviation of the set of observed test scores, *r* = the reliability coefficient for the measurement (ICC).[27] Calculating the SEM allows for estimation of the entire group, based on the established 95% confidence interval. For the purpose of the current study, the SEM provided the expected extent of error in different testers' scores for HHD.

RESULTS

Eleven participants (73% female) met all inclusion criteria, agreed to participate in the study, signed the informed consent, and completed all study parameters. Participants had a mean age 25.2 ± 6.3 years with 18.5 ±6.9 years total dance experience with the seven participants having 9.71 ± 5.43 years of professional dance experience. Tables 1 and 2 provide demographic characteristics and mean values of the observed muscle force production for the reliability study population.

Intra-rater reliability ranged from moderate to high, with ICC values of 0.527-0.851 for Tester 1 and 0.531-0.692 for Tester 2 (Table 3). ICC values for arabesque had generally lower reliability and wider 95% confidence intervals. The SEM was generally low, and ranged from 0.077-0.527, with higher values observed for the arabesque position, suggesting a narrow range of measurement variability could be expected between testers and across positions.

Inter-rater reliability values were high to very high (>0.70), with ICC values ranging from 0.834-0.953 (Table 4). SEM values for the average of three trials per position ranged from 0.034-0.322, with larger values observed for the arabesque position due to higher recorded force values in this position.

DISCUSSION

Inter-rater and intra-rater reliability of the barre-mounted dynanmometer stabilizing device ranged from moderate to very high, supporting the utility of the device in assessing muscle performance in dance-relevant positions. It must be acknowledged that these results should be interpreted with caution due to the limited number of testers. The results are comparable to previous reports of intra-rater reliability of an external stabilizing device for HHD in an athletic population and do not differ from reported HHD reliability.[1-3, 16, 17, 20, 22] Scott et al. evaluated the use of a portable anchoring device for both inter- and intra-rater reliability, and against traditional HHD stabilization in measuring hip flexion, abduction and extension.[1] The authors reported comparable intra-rater reliability to the device in the current study, with ranges of 0.59-0.89 and 0.72-0.89, for a Tester A and B, respectively.[1] The authors also found the portable anchoring device yielded lower ICC values for hip extension, with a reported limitation of testing position, as the participants had difficulty securing contact with the device sensor in prone position.

The observed SEM values suggest a narrow interval of scoring would be anticipated with repeat assessment of dance-relevant position muscle performance though comparison to previous HHD reliability studies is limited. Thorborg et al.[22] reported values of 5-11% for SEM in evaluating the reliability of HHD with an external stabilization belt; however, HHD values were not normalized to height and mass. The HHD values in the current study were considerably lower than cardinal plane hip measures Thorborg et al.[18] reported in an athletic population, and likely account for the lower SEM values. Less force generation is possible when muscles are in their shortened range at 90°. In the current study, arabesque accounted for the largest SEM, likely due to the increased force production capability of the dancers in this position and compensatory recruitment of trunk extensors, as mean values for arabesque were considerably higher than the other two positions.

This study approached a topic with minimal representation in the literature in attempting to identify a reliable means of assessing muscle performance in dancers. Despite the popularity of pre-participation screening in dance institutions across the United States, HHD is not typically included in this assessment, and therefore, normative values for HHD of cardinal plane hip strength in dancers have yet to be reported. Future studies may incorporate HHD to provide a basic understanding of the strength demands required of pre-professional and professional dancers.

Limitations

The introduction of a barre-mounted dynamometer stabilization device is not without limitations. Dancer positioning was monitored to ensure the trunk remained vertical with light stabilization through the upper extremity to minimize potential compensatory force generation through the trunk and spine across test positions. However, it must be noted that contributions of the abdominals and erector spinae were possible.

This was most evident in the ability of two participants to overpower the lever arm stabilization of the device during the second day of data collection. This required additional stabilization by the tester to stop the device from rotating around the ballet barre against extreme force in développé arabesque. The wider confidence intervals and lower intra-rater reliability measures observed for arabesque could have arisen from competitive bias, a learning effect, or a weakness of the device. The participants began trying to exceed the top known scores from initial testing despite the best efforts of the testers to keep individual results private. As previously mentioned, the lower reliability observed in this position could relate to compensatory lumbar lordosis or recruitment of back extensors versus true hip extension, yielding variability in results or change in limb position from leaning forward and losing contact with the dynamometer sensor during testing. The device was consequently modified with a vertical arm to the floor to promote improved stabilization against the larger forces generated in développé arabesque prior to integration in a larger study evaluating the influence of hip pain on muscle performance in dancers.

It must be acknowledged that this device was specifically designed to provide a measure of multiplanar hip muscle performance in in positions that have not previously been documented, rather than quantify isolated hip muscle performance. This may be viewed as a potential limitation of the device. However, weakness in a functional position involving multiple joints could prompt further testing of the individual, synergistic muscles contributing to the motion to identify where the weakness exists. Future iterations of the study may benefit from shortening the lever arm of force application to the distal thigh to eliminate potential of full body compensation during dance specific maneuvers, or testing at each individual’s true mid-range of motion.

Lastly, it should be recognized that the two testers in this study are expert clinicians, and further research across a wider variety of testers would be helpful to improve the generalizability of the results to inexperienced clinicians.

This study was the first of its kind in two ways specific to the dance population: assessing muscle performance in dance-relevant positions and using a barre-mounted dynamometer stabilizing device that can be used within the dance studio. The integrity of the ballet barre or anchoring point for the stabilization device itself could arise as a limitation. The current study included a wall-anchored, rigid ballet barre that did not flex under pressure.

While the positions selected are completed at high frequency in both technique classes and rehearsals, it is not known if these are the most representative of the strength demands for sustaining gesture limb positions. Use of surface electromyography (EMG) could better inform muscle firing patterns required for each movement; however, this was beyond the scope of the current study. The novel design of the stabilization device provides an efficient, cost-effective and portable means of better understanding the unique strength demands dance requires.

CONCLUSION

The observed findings suggest muscle performance of dance specific maneuvers of développé en avant and a la secondé can be reliably measured with a barre-mounted dynamometer stabilizing device. The device is easily portable and can be easily adjusted to accommodate ballet barres of variable diameters. Further investigation of an improved means of stabilization for développé arabesque should be considered to improve reliability. The device may have broader applicability in the genre of athletes such as figure skaters and gymnasts who require positions and maneuvers requiring a larger range of hip motion and multi-joint stability. The device has value in eliminating differences in strength among testers, particularly when the device could be integrated into pre-participation screenings and testing across different geographic locations. The device has potential utility in the general population, as it could be anchored to a railing or parallel bars in a standard physical therapy clinic setting.

Broader applications of this device may help establish normalized data for dance specific muscle performance measures, and potentially be used to identify strength impairments in the dance population. Future research efforts may focus on modifications to the original device to allow for greater generalizability and adaptability in measuring both upper and lower extremity muscle force production and incorporating the use of surface EMG during dance specific movements to improve our understanding of the muscle activation required for the physical demands dance requires.

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Figure 1: Study Equipment

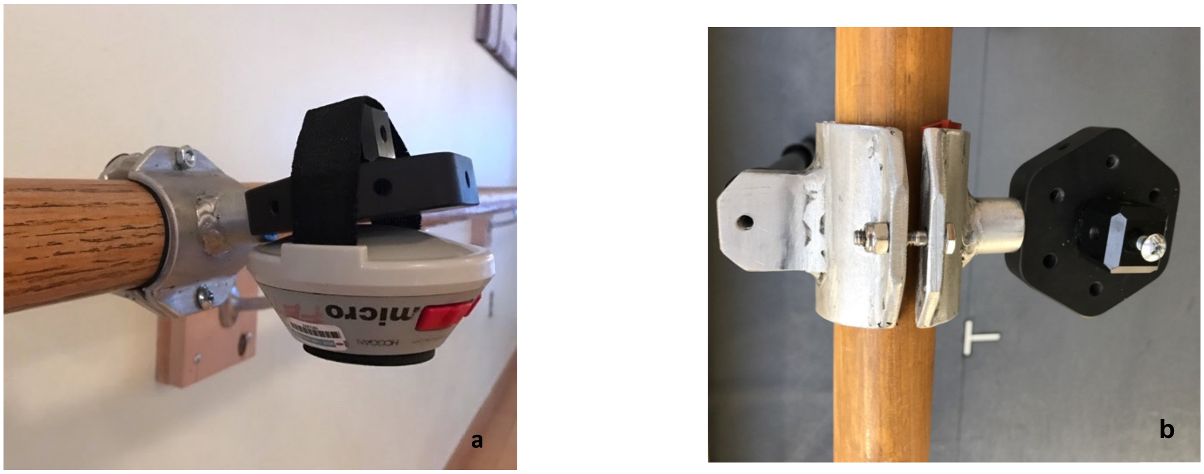

FIGURE 1a-b: DynaRail anchoring system and Hoggan Scientific, LLC. microFET®2 digital handheld dynamometer muscle tester. The dynamometer is attached to the disc device with Velcro squares and elastic band.

a b c

Figures 2a-2c Test positions:2a) Développé en avant (front); 2b) Développé a la secondé (side); 2c)

Figure 4: Test position for développé arabesque (back).

TABLE 1: Study Demographics

	Female	**Male**	**Total**
Participants (%)*	8 (72.7%)	3 (27.3%)	11 (100%)
Professional dancers (%)	5 (45.5%)	2 (18.2%)	7 (63.7%)
Pre-Professional/Student (%)	3 (27.3%)	1 (9.1%)	4 (36.4%)
Age (yrs)	24.0 ± 5.43	28.33 ± 8.51	25.2 ± 6.30
Dance training (yrs)	18.13 ± 6.79	19.33 ± 8.62	18.45 ± 6.89
Professional experience (yrs)[+]	8.50 ± 5.36	12.75 ± 6.01	9.71 ± 5.43
Weight (kg)	51.48 ± 4.33	66.53 ± 3.46	55.6 ± 8.06
Height (m)	1.65 ± 0.06	1.72 ± 0.02	1.67 ± 0.06

*All percentages are given as % of the total. Abbreviations: yrs=years, m=meters, kg=kilograms.
[+]*Mean of 7 subjects with professional experience.*

TABLE 2: Mean muscle force production by Day, Position and Tester

	Day 1: Mean±SD	Day 2: Mean±SD
Développé en avant/*Front*		
Tester 1	1.102 ± 0.293	1.292 ± 0.401
Tester 2	1.106 ± 0.273	1.338 ± 0.360
Développé a la seconde/*Side*		
Tester 1	1.135 ± 0.383	1.408 ± 0.442
Tester 2	1.101 ± 0.246	1.390 ± 0.437
Développé arabesque/*Back*		
Tester 1	2.303 ± 0.724	3.628 ± 1.155
Tester 2	2.333 ± 0.823	3.637 ± 0.762

Isometric muscle force production (Nm) was normalized by body weight (N) x height (m) x 100; SD = Standard Deviation

TABLE 3: Intra-rater Reliability by Position and Tester

Intra-rater Reliability	ICC (95% CI)	SEM
Développé en avant/*Front*		
Tester 1	0.851 (0.177 - 0.964)	0.077
Tester 2	0.692 (-0.096 - 0.917)	0.148
Développé a la seconde/*Side*		
Tester 1	0.739 (-0.006 - 0.931)	0.164
Tester 2	0.624 (-0.197 - 0.895)	0.198
Développé arabesque/*Back*		
Tester 1	0.527 (-0.240 - 0.870)	0.527
Tester 2	0.531 (-0.104 - 0.881)	0.302

ICC = r value (intraclass correlation coefficient); CI=Confidence Interval; SEM = Standard Error of Measurement. Isometric muscle force production (Nm) was normalized by body weight (N) x height (m) x 100.

TABLE 4: Inter-rater Reliability by Position and Day

Inter-rater Reliability	ICC (95% CI)	SEM
Développé en avant/*Front*		
Day 1	0.843 (0.391 - 0.958)	0.085
Day 2	0.954 (0.838 - 0.988)	0.034
Développé a la seconde/*Side*		
Day 1	0.834 (0.371 - 0.956)	0.102
Day 2	0.953 (0.823 - 0.987)	0.042
Développé arabesque/*Back*		
Day 1	0.858 (0.454 - 0.962)	0.213
Day 2	0.828 (0.329 - 0.954)	0.322

ICC = r value (intraclass correlation coefficient); CI=Confidence Interval; SEM = Standard Error of Measurement. Isometric muscle force production (Nm) was normalized by body weight (N) x height (m) x 100.