Reliability of electromyographic normalization methods for evaluating the hip musculature

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Abstract

The purpose of this study was to determine the reliability of three normalization methods for analyzing hip abductor activation during rehabilitation exercises. Thirteen healthy subjects performed three open kinetic chain and three closed kinetic chain hip abductor exercises. Surface EMG activity for the gluteus medius was collected during each exercise and normalized based on a maximum voluntary isometric contraction (MVIC), mean dynamic (m-DYN), and peak dynamic activity (pk-DYN). Intraclass coefficient correlations (ICCs), intersubject coefficients of variation (CVs), and intrasubject CVs were then calculated for each normalization method. MVIC ICCs exceeded 0.93 for all exercises. M-DYN and pk-DYN ICCs exceeded 0.85 for all exercises except for the sidelying abduction exercise. Intersubject CVs ranged from 55% to 77% and 19% to 61% for the MVIC and dynamic methods, respectively. Intrasubject CVs ranged from 11% to 22% for all exercises under all normalization methods. The MVIC method provided the highest measurement reliability for determining differences in activation amplitudes between hip abductor exercises in healthy subjects. Future research should determine if these same results would apply to a symptomatic patient population.

1. Introduction

Therapeutic exercise is one of the most important treatment modalities used by rehabilitation professionals. They have analyzed electromyographic (EMG) muscle activity during exercise and theorized that exercises that produce higher activation amplitudes would benefit patients. Although many studies have investigated amplitudes during knee [18,21,22,28,42] and shoulder [6,34,41,45] exercises, none have determined amplitudes during hip abduction exercises. Hip abduction (HA) exercises have important functional implications because they enable patients to regain the muscle strength needed for performing activities of daily living and sports.

EMG normalization is required to compare muscle activity among different subjects. Prior studies have normalized EMG signals based on a maximum voluntary isometric contraction (MVIC); however, this method has certain limitations like the assumption that subjects provided a maximum effort during testing and that activation represented total muscle activity required for the task [48,49]. Other investigations have normalized muscle activity based on mean dynamic or peak dynamic amplitudes because these methods patterned muscle activation produced during the specific task [5,33,36,47,49]. In addition, dynamic methods may be more appropriate for patients who cannot safely perform a MVIC.

Reliability is the extent to which measurements are consistent, dependable, and free from error [17,39]. It also refers to the stability and consistency of measures with respect to time so that variations between measures result from changes in the variable being measured [25].
respect to EMG analysis of rehabilitation exercises, measurement variations should represent true differences in muscle activity among each exercise condition. Therefore, researchers should normalize muscle activity using the most reliable method in order to make appropriate inferences regarding muscle activation.

Prior works have examined the reliability of EMG normalization methods during gait \[5,11,47,49\] and single leg stance tasks \[26\] based on a MVIC and dynamic activities and calculated intraclass correlation coefficients (ICCs), intersubject coefficients of variation (CVs), and intrasubject CVs to establish measurement reliability. Some researchers \[11,26\] recommended a MVIC method because it represented absolute demands required for a specific task; others advocated a dynamic method because it reduced intersubject variability and provided information on the pattern of muscle activation during a task \[47,49\].

One should note that many factors might affect the interpretation of EMG activity \[29\]. Heckathorne and Childress \[23\] demonstrated how changes in muscle length and rate of change altered the magnitude of EMG amplitudes. Generally, amplitudes were greater during concentric (shortening) muscle contractions, compared to isometric contractions, because muscle fibers had greater difficulty producing force in a shortened state \[1,32\]. Likewise, eccentric (lengthening) muscle contractions produced less EMG activity because of a more favorable length–tension relationship of the actin-myosin cross bridges \[1,32\]. Therefore, changes in a muscle’s length–tension relationship accounted for higher EMG amplitudes observed during dynamic contractions. The rate of change of force also influenced EMG amplitudes; EMG for a given force level generally increased as velocity decreases \[23\]. Because of these confounding factors, it is unknown how they might affect the reliability of normalization methods.

Recently, clinicians have reported on the importance of the HA musculature in lower extremity rehabilitation programs \[19,24,30,37\]. In determining which exercises best activate the HA musculature, researchers must use a normalization method that will provide reliable information. Therefore, the purpose of this study was to examine measurement reliability of HA amplitudes during six rehabilitation exercises using a MVIC, mean dynamic, and peak dynamic normalization method.

### 2. Methods

#### 2.1. Participants

We used data obtained from 13 healthy subjects (7 men, 6 women; age = 24 ± 7 years; height = 1.6 ± 0.2 m; weight = 765.2 ± 137.3 N) who participated in a larger study that examined muscle activation amplitudes during HA rehabilitation exercises \[9\]. They represented a sample of convenience recruited from the local University community. Subjects participated in the study only if they if they had no lower extremity dysfunction and could safely perform a single leg stance on each lower extremity. Subjects could not participate if they had a history of significant lower extremity injury or surgery in the preceding year. The primary investigator explained the testing procedures and associated risks and benefits specific to the study to all subjects. Participants signed their voluntary decision to participate by signing a University-approved informed consent form.

#### 2.2. Subject preparation

The principal investigator prepared subjects' skin for the surface EMG electrodes in a standard manner \[4\]. Bipolar Ag/AgCl surface electrodes (Medicotest, Rolling Meadows, IL) were placed one-half the distance between the iliobial crest and greater trochanter over the muscle belly of the right gluteus medius (GM) because placement in this manner can minimize the recording of activity from the nearest motor unit action potential and minimize musculature interference \[4,13\]. Surface electrodes, placed parallel to the GM muscle fibers, measured 5 mm in diameter and had a 20 mm inter-electrode distance. The principal investigator also donned a ground electrode on the ipsilateral acromion process. The principal investigator visually confirmed the electrical signal on an oscilloscope using common manual muscle testing techniques and secured the electrodes with electrode tape to prevent slippage during testing. Finally, a two-dimensional electrical goniometer was placed on the lateral aspect of the right and left hips over the greater trochanter for purposes of delineating repetitions during exercise.

#### 2.3. Protocol

Subjects reported to the Musculoskeletal Laboratory for a single occasion testing session. Prior to testing, subjects rode a stationary bike at a submaximal speed for 5 min. They also performed gentle hamstring, calf, and quadriceps stretching consisting of five repetitions with a 15 s hold. Next, subjects practiced each exercise to the beat of a metronome (60 beats per minute) to familiarize themselves with each task (see Table 1). For each exercise, we also demarcated the appropriate range of motion using wooden blocks. Subjects performed each exercise until they demonstrated proficiency as determined by the researchers and rested 10 min prior to testing to reduce fatigue. The principal investigator implemented these warm-up activities to ensure that all subjects performed each exercise in a standardized and correct manner during testing.

Since clinicians typically use both open kinetic chain (OKC) and closed kinetic chain (CKC) exercises in rehabilitation programs, we included three variations of each type exercise. For the OKC exercises, we donned a cuff weight equal to 3% body weight on subjects' right ankle. For the CKC exercises (except the pelvic drop), we placed the same weight on subjects' left ankle. We used an ankle weight because it provided a known mass throughout the entire range of motion for each exercise.
Subjects performed 15 repetitions of each exercise to a metronome set at 60 beats per minute and in a standardized manner to ensure similar rates and ranges of motion among subjects [42]. For the hip sidelying and standing abduction exercises, subjects raised the specific lower extremity on one beat, lowered it on the next, and rested one beat, a sequence they repeated for 15 repetitions. For the pelvic drop exercise, subjects lowered the left pelvis toward the floor in order to adduct the right hip. Subjects then contracted the right GM to return the pelvis to a level position.

### Table 1

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing hip abduction</td>
<td>Subjects stand with both lower extremities 10 cm apart. They abduct the right lower extremity 25 degrees and adduct it to the starting position during this exercise, while standing solely on the left lower extremity with the pelvis in a level position.</td>
</tr>
<tr>
<td>Standing hip abduction with flexed hip</td>
<td>Subjects stand with both lower extremities 10 cm apart with the hips and knees in 20° of flexion. They abduct the right lower extremity 25 degrees and adduct it to the starting position during this exercise, while standing solely on the left lower extremity with the pelvis in a level position.</td>
</tr>
<tr>
<td>Single leg stance with contralateral load [27]a</td>
<td>Subjects stand with both lower extremities 10.16 cm apart. They abduct the left lower extremity 25 degrees and adduct it to the starting position during this exercise, while standing solely on the right lower extremity with the pelvis in a level position.</td>
</tr>
<tr>
<td>Sidelying hip abduction [15,23]</td>
<td>Subjects lie on their left side with the right lower extremity parallel to the left one. They abduct the right lower extremity to 25 degrees and adduct it to the starting position during this exercise.</td>
</tr>
<tr>
<td>Single leg stance with contralateral load and flexed hipa</td>
<td>Subjects stand with both lower extremities 10.16 cm apart with the hips and knees in 20° of flexion. They abduct the left lower extremity 25 degrees and adduct it to the starting position during this exercise, while standing solely on the right lower extremity with the pelvis in a level position.</td>
</tr>
<tr>
<td>Pelvic drops [15]</td>
<td>Subjects stand solely on the right lower extremity on a 6° step. With both knees in a fully extended position, they lower the left pelvis toward the floor in order to adduct the right hip. Subjects then contract the right GM to return the pelvis to a level position.</td>
</tr>
</tbody>
</table>

*a Cuff weight donned on the left ankle.

2.3.1. Reference muscle activation for normalization

We determined reference values both before and after exercise for purposes of establishing measurement reliability. To determine reference values for the MVIC normalization method, subjects assumed a left sidelying position with the right lower extremity in 25 degrees of hip abduction as determined through goniometric measurement. We maintained this position by placing pillows between each subject’s lower extremities and securing them with a mobilization (immovable) strap over the lateral femoral condyle (see Fig. 1). A mobilization strap was used since previous works have demonstrated the reliability of this
method for producing a maximum contraction for the hip abductors [24,27,35,46]. We chose 25 degrees of hip abduction as our reference point since this position has been commonly used for manual muscle testing [15].

The principal investigator instructed subjects to generate maximum hip abductor force using the “make test” [2,7]. For the “make test,” subjects generated maximum hip abductor force over a 2 s period and held the maximum contraction for a 5 s period. Prior to testing, subjects familiarized themselves with the test position and sequence by performing two submaximal isometric contractions. For testing purposes, subjects performed three MVICs using the “make test” and rested 1 min between each effort to minimize fatigue. The principal investigator provided strong verbal encouragement to facilitate subjects’ ability to perform a MVIC [12]. To determine reference values for the mean and peak dynamic normalization methods, subjects performed 15 repetitions of active right hip abduction (0–25 degrees) in the sidelying position with no load (no ankle weight) at a rate of 60 beats per minute. We randomized order for determining reference muscle activation to reduce ordering bias.

2.4. EMG data reduction

2.4.1. MVIC

Using the three MVICs performed by each subject, we determined the maximum root mean squared (RMS) amplitude recorded over a 500 millisecond (ms) window [3], which represented 100% MVIC amplitude. For each exercise condition, we calculated the RMS amplitude for each repetition and expressed each as a percentage of the MVIC (% MVIC). We normalized EMG signals from each exercise a second time using the post-testing MVIC value for purposes of calculating ICCs. The % MVIC for the last 10 repetitions (pre- and post-testing MVIC) for each exercise were then averaged and used for statistical analysis.

2.4.2. Mean dynamic activity

EMG signals collected during the 15 repetitions of the unloaded (no ankle weight) sidelying HA exercise were full wave rectified and linear smoothed using a 250 ms time constant with Datapac software [5]. The mean amplitude for this linear envelope was determined and represented 100% mean dynamic amplitude (m-DYN). For each exercise condition, we processed signals using this linear envelope, calculated the mean amplitude, and expressed these amounts as a percentage of the m-DYN (% m-DYN). We normalized EMG signals from each exercise a second time using the post-testing m-DYN value for purposes of calculating ICCs. The % m-DYN for the last 10 repetitions (pre- and post-testing m-DYN amplitudes) for each exercise were then averaged and used for statistical analysis.

2.4.3. Peak dynamic activity

EMG signals collected during the 15 repetitions of the unloaded (no ankle weight) sidelying HA exercise were full wave rectified and linear smoothed using a 250 ms time constant with Datapac software [5]. The peak amplitude for this linear envelope was determined and represented 100% peak dynamic amplitude (pk-DYN). For each exercise condition, we processed signals using this linear envelope, calculated the peak amplitude for each repetition, and expressed these amounts as a percentage of the pk-DYN (% pk-DYN). We normalized EMG signals from each exercise a second time using the post-testing pk-DYN value for purposes of calculating ICCs. The % pk-DYN for the last 10 repetitions (pre- and post-testing pk dynamic amplitudes) for each exercise were then averaged and used for statistical analysis.

2.5. Statistical analysis

MVIC reliability was assessed to ensure that electrodes did not displace during each testing session [31,40]. To evaluate reproducibility, the intraclass correlation coefficient (ICC) (model [2,1]) [43] was calculated using the maximal 500 ms of RMS amplitude generated during the pre-testing and the post-testing MVICs.

To determine measurement reliability for each exercise condition, we calculated separate ICCs (model [2,10]) [43] using the pre-testing and post-testing % MVIC, % m-DYN, and % pk-DYN values. We also calculated the standard error of measure (SEM) to describe the precision of each measurement [16]. All statistical analyses were conducted using SPSS Version 12.0 (SPSS Inc., Chicago, IL) at the 0.05 level of significance.

Although not a measure of reliability, intersubject CVs are inversely related to reproducibility and have been used as a criteria for selecting a particular normalization method [10,11,26,47,49]. We calculated intersubject CVs for each exercise condition by dividing the overall standard deviation by the grand mean (Intersubject CV = s/X) using values derived from each pre-testing % MVIC, % m-DYN, and % pk-DYN normalization method [38].

The % MVIC for the last 10 repetitions (pre- and post-testing MVIC) for each exercise were then averaged and used for statistical analysis...
We determined intrasubject reliability using the middle five repetitions that subjects performed for each exercise. We first determined the total mean square error (MSE) by performing separate analyses of variance (ANOVA) with repeated measures on values determined under each normalization method using SPSS Version 12.0 (SPSS Inc.) at the 0.05 level of significance. We then calculated intrasubject CVs for each exercise by dividing the square root of the overall MSE by the mean EMG activity (Intra-subject CV \( = \sqrt{\text{MSE}/\bar{x}} \)) using values from each pre-testing normalization method [26].

3. Results

ICCs ranged from 0.93 to 0.96 using the MVIC method, 0.41 to 0.97 using the mean dynamic method, and 0.71 to 0.98 using the peak dynamic method. Table 4 summarizes the intersubject and intrasubject CVs. Intersubject CVs ranged from 55% to 77% using the MVIC method, 19% to 44% for the mean dynamic method, and 26% to 61% using the peak dynamic method. Intrasubject CVs ranged from 11% to 22% for all methods.

4. Discussion

Clinicians [14,19,20,30,37] have recognized the role of the HA musculature when developing successful rehabilitation programs. Although exercise prescription is an important intervention, only a single study [9] has examined EMG amplitudes of the hip musculature during therapeutic exercises. Information regarding HA activation during

<table>
<thead>
<tr>
<th>Exercise</th>
<th>% MVIC</th>
<th>% m-DYN</th>
<th>% pk-DYN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD(^a)</td>
<td>Mean</td>
</tr>
<tr>
<td>Sidelying abduction</td>
<td>40</td>
<td>22</td>
<td>59</td>
</tr>
<tr>
<td>Standing abduction</td>
<td>30</td>
<td>21</td>
<td>38</td>
</tr>
<tr>
<td>Standing abduction with 20° hip flexion</td>
<td>27</td>
<td>20</td>
<td>32</td>
</tr>
<tr>
<td>Pelvic drop</td>
<td>54</td>
<td>30</td>
<td>84</td>
</tr>
<tr>
<td>Single leg stance with contralateral load</td>
<td>40</td>
<td>26</td>
<td>58</td>
</tr>
<tr>
<td>Single leg stance with contralateral load and 20° hip flexion</td>
<td>44</td>
<td>34</td>
<td>62</td>
</tr>
</tbody>
</table>

\(^a\) SD: standard deviation.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>MVIC</th>
<th>m-DYN</th>
<th>pk-DYN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC</td>
<td>SEM(^a)</td>
<td>ICC</td>
</tr>
<tr>
<td>Sidelying abduction</td>
<td>0.93</td>
<td>5</td>
<td>0.41</td>
</tr>
<tr>
<td>Standing abduction</td>
<td>0.96</td>
<td>4</td>
<td>0.85</td>
</tr>
<tr>
<td>Standing abduction with 20° hip flexion</td>
<td>0.96</td>
<td>4</td>
<td>0.93</td>
</tr>
<tr>
<td>Pelvic drop</td>
<td>0.95</td>
<td>6</td>
<td>0.95</td>
</tr>
<tr>
<td>Single leg stance with contralateral load</td>
<td>0.96</td>
<td>4</td>
<td>0.97</td>
</tr>
<tr>
<td>Single leg stance with contralateral load and 20° hip flexion</td>
<td>0.96</td>
<td>6</td>
<td>0.95</td>
</tr>
</tbody>
</table>

\(^a\) SEM stated as a % EMG activity based on each normalization method.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>MVIC</th>
<th>m-DYN</th>
<th>pk-DYN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inter (%)</td>
<td>Intra (%)</td>
<td>Inter (%)</td>
</tr>
<tr>
<td>Sidelying abduction</td>
<td>55</td>
<td>12</td>
<td>19</td>
</tr>
<tr>
<td>Standing abduction</td>
<td>70</td>
<td>18</td>
<td>22</td>
</tr>
<tr>
<td>Standing abduction with 20° hip flexion</td>
<td>74</td>
<td>17</td>
<td>35</td>
</tr>
<tr>
<td>Pelvic drop</td>
<td>56</td>
<td>11</td>
<td>39</td>
</tr>
<tr>
<td>Single leg stance with contralateral load</td>
<td>65</td>
<td>11</td>
<td>44</td>
</tr>
<tr>
<td>Single leg stance with contralateral load and 20° hip flexion</td>
<td>77</td>
<td>11</td>
<td>37</td>
</tr>
</tbody>
</table>
rehabilitation exercises will assist clinicians in exercise prescription.

Historically, clinicians have utilized lower extremity therapeutic exercises on the assumption that those exercises that produce higher EMG amplitudes will produce greater strengthening effects. These studies [18,21,22,28,42] have based recommendations on data expressed as a % MVIC without examining measurement reliability. Reliability means that measurement methods should detect differences in % EMG amplitudes that resulted from changes in the variable (exercise) being examined [25]. Reliability is also analogous with reproducibility, meaning that others should obtain similar measures with testing replication [26].

With respect to upper extremity exercise, investigators have examined the reproducibility of isometric and dynamic normalization methods. Morris et al. [33] reported that the mean and peak dynamic normalization methods provided more reproducible measures compared to those using a MVIC. Based on these findings, we wanted to determine if an isometric or dynamic normalization method would provide greater measurement reliability when investigating HA activation amplitude during therapeutic exercises.

4.1. Normalization based on a MVIC

Prior work [18,26] has shown that use of the MVIC method can provide a reliable measure of muscular demands during a specific lower extremity task or exercise. Earl et al. [18] examined quadriceps activation during dynamic mini-squat exercises and reported ICCs of 0.99 when using a MVIC reference value, which agree with the present study’s calculations (ICCs ≥ 0.93). High ICCs infer not only good measurement reliability but also reasonable validity [39]. The MVIC normalization method also resulted in low SEMs, which inferred acceptable measurement precision and stability when using this method [16].

Intersubject CVs are inversely related to reproducibility, and researchers [47,49] have used them as a criteria for selecting a particular normalization method. Although intersubject CVs are not a measure of reliability, we calculated them to compare results to other studies [10,26,47,49]. The present study’s intersubject CVs, which ranged from 55% to 77% in the present study, are relatively large but agree with those reported by Knutson et al. [26]. These researchers analyzed gastrocnemius EMG activity during a single leg stance activity and calculated an intersubject CV of 91.3%. They also emphasized that large intersubject CVs are not necessarily “good or bad” because data variability is required to identify differences. Knutson et al. [26] also stated that lower intersubject CVs might infer group homogeneity and limit comparisons of results to future studies.

Yang and Winter [49] advocated using normalization methods that reduce intersubject variability in their studies designed for establishing normative values of muscle acti-

vation during gait. The purpose of their studies was to provide patterns of muscle activation that clinicians could use in identifying patient gait abnormalities. Our higher intersubject CVs may contradict Yang and Winter’s recommendations; however, the purpose of the present study was to determine differences in muscle demands, not patterns of activation, during HA exercise [11,26]. Therefore, intersubject CVs provided limited information regarding measurement reliability.

Intrasubject CVs relate more to measurement reproducibility and stability because they are calculated from subject repeated measures and may detect measurement error [26]. We examined repeatability using the middle five repetitions for each exercise; values calculated for all normalization methods were less than 20%. Our calculations mirrored those employed in the Knutson study [26] and were well below the 38.1% value reported by these researchers.

In summary, we believe that studies that investigate HA muscle activation using a healthy group of subjects should continue using a MVIC normalization method. The combination of high ICCs, lower SEMs, and low intersubject CVs associated with data expressed as a % MVIC inferred high measurement reliability.

4.2. Normalization based on dynamic activities

A potential limitation with using a MVIC reference value is that symptomatic subjects cannot perform a maximum contraction because of pain and muscle inhibition. Dynamic methods based on mean or peak muscle activity do not depend on a maximal contraction, and previous work [11,47,49] has shown that these methods may provide a better representation of the muscle activity required for a specific task. Furthermore, Yang and Winter [49] have recommended dynamic methods because they produce lower intersubject CVs, which may increase surface EMG sensitivity when analyzing gait.

ICCs calculated for each exercise using the dynamic methods exceeded 0.85 except for the sidelying abduction exercise. For this exercise, we calculated ICCs of 0.41 and 0.71 for the m-DYN and pk-DYN methods, respectively. Although we cannot conclusively determine the reason for these findings, we can make the following inference. This exercise was the only one that patients did not perform in a standing position. We made every effort to ensure that subjects performed this exercise with both lower extremities positioned parallel to each other; however, they could have moved the right extremity in an anterior position. Such changes in position could have resulted in a different recruitment of motor units that negatively affected the ICC calculations.

Intersubject CVs ranged from 19% to 44% using the m-DYN method and from 26% to 61% using the pk-DYN method, ranges similar to those reported by others [11,26,49] who used mean and peak dynamic normalization.
methods. A comparison of intersubject CVs for individual exercises demonstrated that the MVIC method had greater variability than the dynamic methods. With respect to the dynamic methods, the m-DYN method had lower intersubject CVs than the pk-DYN method. These findings support previous findings that revealed lower intersubject CVs when normalizing EMG using a m-DYN method [11,26,49].

Intrasubject CVs were less than 19% and 23% for the m-DYN and pk-DYN methods, respectively. Although Knutson et al. [26] reported intrasubject CVs ranging from 23% to 31% when analyzing gastrocnemius activity, we found greater intrasubject reproducibility of data with repeated measures using both dynamic normalization methods. See Fig. 2 for a comparison of intrasubject measurement repeatability using each normalization method.

We believe that the m-DYN method may provide a more reliable measurement of EMG data compared to the pk-DYN. With respect to ICCs, the sidelying exercise had a lower m-DYN ICC value and a lower (more precise) SEM. ICC calculations are based on data variability [39], meaning that differences are more difficult to detect when using less variable data. In our study, a lower SEM may have accounted for a lower ICC value [8]. All other ICCs were acceptable and similar between methods for the remaining exercises.

A comparison of CVs for both methods revealed that the m-DYN method resulted in lower intersubject (see Table 4) and intrasubject CVs (see Fig. 2). Together, these results inferred greater stability of measures using the m-DYN method and agree with previous studies [26,47,49]. Based on the calculated ICCs and CVs, we believe that

![Fig. 2. Comparison of hip abductor musculature amplitude patterns for each exercise (A) sidelying abduction, (B) standing hip abduction, (C) standing hip abduction with 20° hip flexion, (D) pelvic drop, (E) single leg stance with a contralateral load, and (F) single leg stance with a contralateral load in 20° hip flexion based on a percentage of maximum voluntary isometric contraction (MVIC), mean dynamic activity (m-DYN), and peak dynamic activity (pk-DYN).]
the m-DYN method provided greater measurement reliability than the pk-DYN method when evaluating HA muscle activation amplitudes during therapeutic exercises.

4.3. Comparison of EMG amplitudes between normalization methods

The MVIC method had lower percent EMG amplitudes compared to dynamic methods. We expected these lower values because subjects performed exercises requiring submaximal muscular effort. To perform a MVIC, subjects required higher levels of motor unit recruitment. Therefore, the percent EMG activity required for submaximal exercise would be much lower when normalized to higher EMG MVIC activation levels. For the dynamic normalization methods, subjects performed a sidelying hip abduction exercise with no weight applied to the lower extremity, a task that required less EMG activity than a MVIC. Based on this information, we expected greater percent EMG activation using dynamic normalization methods. During testing, subjects performed non-weight bearing with an ankle weight and weight bearing HA exercises, which placed greater demands on the hip abductors than the reference sidelying exercise. Therefore, the percent EMG activity calculated using the dynamic methods would be higher because the reference activation level was less than that during a MVIC.

4.4. Limitations

The current study has certain limitations that we would like to address. An inherent limitation associated with MVIC normalization has been the assumption that subjects provide a maximal effort. To facilitate a MVIC, we positioned subjects in a manner consistent with standard manual muscle testing techniques in combination with resistance from an immovable object (firmly secured mobile object). Prior replication to symptomatic subjects, researchers may need different motor unit recruitment patterns.

Finally, we cannot generalize our findings to symptomatic subject populations. Our findings revealed that the MVIC method provided the most reliable measures, which agreed with other studies [18,26]. We also found acceptable reliability measures for the m-DYN method. Although we would expect to find similar HA activation amplitudes using symptomatic subjects, we cannot make this conclusion based on results from the present study.

5. Conclusion

To our knowledge, this study was the first to examine the reliability of normalization methods that researchers may use to determine muscle activation during HA therapeutic exercises. Historically, investigators have examined muscle amplitudes using healthy subjects and have inferred similar findings to symptomatic subject populations. Future studies should examine muscle activation in subjects diagnosed with pathology in order to generalize findings because symptomatic subjects may demonstrate different motor unit recruitment patterns.

Our results demonstrated that the MVIC normalization method provided greater measurement reliability for evaluating activation amplitudes during HA exercise. With study replication to symptomatic subjects, researchers may need an alternative method to evaluate exercise if subjects cannot elicit a valid MVIC because of pain and muscle inhibition. In these cases, researchers should consider using the m-DYN method because it can identify HA amplitude differences among exercises but with little risk of injury or discomfort to symptomatic subjects.

References


Dr. Lori A. Bolgla is assistant professor in the Department of Physical Therapy, School of Allied Health Sciences at the Medical College of Georgia. Dr. Bolgla received her Bachelor in Science degree in physical therapy from the Medical College of Georgia in 1993 and her Master in Science degree in physical therapy from the Medical College of Georgia in 1998. She received her doctor of philosophy degree in Rehabilitation Sciences from the University of Kentucky in 2005. Her research has focused on the evaluation and rehabilitation of lower extremity overuse injuries.

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