Electromyography Normalization Methods for High-Velocity Muscle Actions: Review and Recommendations

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Electromyograms used to assess neuromuscular demand during high-velocity tasks require normalization to aid interpretation. This paper posits that, to date, methodological approaches to normalization have been ineffective and have limited the application of electromyography (EMG). There is minimal investigation seeking alternative normalization methods, which must be corrected to improve EMG application in sports. It is recognized that differing normalization methods will prevent cross-study comparisons. Users of EMG should aim to identify normalization methods that provide good reliability and a representative measure of muscle activation. The shortcomings of current normalization methods in high-velocity muscle actions assessment are evident. Advances in assessing alternate normalization methods have been done in cycling and sprinting. It is advised that when normalizing high-intensity muscle actions, isometric methods are used with caution and a dynamic alternative, where the muscle action is similar to that of the task is preferred. It is recognized that optimal normalization methods may be muscle and task dependent.

Keywords: EMG, maximum voluntary contractions, reliability, sprint cycling, sprinting

Sport- and exercise-based activities frequently require the human body to exert maximal forces in a short amount of time to achieve the desired goal. Activities such as sprinting, cycling or Olympic lifting movements require a high-velocity coordinated maximal effort to complete the task successfully.1–3 Understanding the neuromuscular requirements of these actions enables relevant practitioners, coaches and trainers to gain a better understanding of muscular contributions and control pattern, that will allow technique modification and inform training practices. Furthermore, assessment of maximal effort events affords us an insight in to the neuromuscular limits, capabilities and processes involved in conducting high-velocity human movement. The most common method of directly assessing neuromuscular contribution to any task is through electromyography (EMG).4

Owing to well-documented intrinsic and extrinsic factors influencing the collection of EMG data and the variance that occurs in the collected signal, the process of EMG normalization is universally advocated for temporal EMG data processing.4 Normalization of an EMG involves rescaling the data to a percent of a selected reference value, (task EMG / reference EMG) × 100.5–9 Normalization is an important component of EMG studies that look to express the relative neuromuscular capacity of the muscle during a task, to enable between muscle, between study and between subject comparisons9–11 and to improve the intra/interindividual variability of the unnormalized EMG.7,12,13 Lehman and McGill14 demonstrated the misinterpretation of unnormalized EMG data from sections of the rectus abdominis during exercise, and showed normalized data to provide a more realistic insight into the muscular contribution during a task, thus highlighting the importance of normalization in EMG data collection.

A recent review article by Burden15 commented on the progress of EMG normalization methods in the preceding 25 years. The article focused mainly on normalizing EMG from low-intensity actions such as gait, isolated muscle exertions and occupational tasks. It concluded that normalizing task-based EMG to a maximum voluntary isometric contraction (MVIC) is preferable as a reference value due to methodological simplicity, proposed reliability and its supposed ability to generate maximum EMG amplitudes. While this statement may be true for low-velocity muscle actions, activities that require power and a high-velocity exertion (sprinting/jumping) may need an alternative approach, as past research has consistently shown the increased neuromuscular requirements in high-velocity maximal efforts compared with submaximal efforts.16–20 Thus an MVIC may produce appropriate EMG values to represent relative activation for low-velocity tasks;21,22 however, in high-velocity tasks, these EMG values may be insufficient. This inability to express relative neuromuscular capacity has been shown in previous literature pertaining to sprinting;23–25 however, in cycling, the successful use of an MVIC is...
inconclusive.26–28 Furthermore, the intrasubject reliability of MVIC normalization methods between testing sessions over 1 week is inconclusive thus questioning its ability to reflect changes in neural drive,24 and prompting the need for further investigation into normalization for such tasks.

In addition to previous literature supporting the improvement of normalization processes for high-velocity muscle actions,29 there are physiological processes that are more prominent or only occur at high levels of effort, which can influence the associated EMG signal in terms of shape or magnitude. These factors question the use of a normalization method endorsed based on low-velocity muscle action application and include (a) muscle movement in relation to the electrode,30–33 (b) impact artifacts and perspiration involved in tasks high-velocity tasks,33 (c) amplitude cancellation,34,35 (d) rapid recruitment and de-recruitment of motor units,31,34 (e) increased velocity of muscle actions reducing the time for cross-bridge formations,36 (f) increased velocity of movement37,38 and (g) the low fatigue resistance of fast twitch motor units which are preferentially recruited in dynamic actions.39

Due to the increasing use of electromyography in sports-based actions and to facilitate the interpretation of the EMG to assess high-velocity muscle actions (eg, during sprinting, jumping, plyometrics and cycling)23,25,27,40–43 a review of the normalization procedures used for high-velocity muscle actions is required. This brief review article aims to assess current practice within normalization methods with reference to high-velocity muscle actions and the issues facing selection of this method. The review will then review current practice within 2 high-velocity actions: sprinting and sprint cycling.

**Current EMG Normalization Methods Used in High-Velocity Dynamic Actions**

In 1993, Clarys and Cabri6 showed that 23% of electromyography studies reviewed normalized task EMGs in sports actions using an MVIC, and 17% used peak dynamic normalization. The most common methods of EMG normalization currently used for the assessment of EMG in high-velocity muscle actions are (1) isometric maximum voluntary muscle action (the MVIC); peak EMG from a static muscle action,23 (2) peak dynamic; Peak EMG from the task under investigation,44 (3) mean dynamic: mean EMG from the task under investigation,45,46 and (4) nonsymmetric maximal effort: peak EMG from separate dynamic action with similar neural drive.27,47–49 Normalization methods using a isometric submaximum voluntary muscle action,50 an isometric angle-specific EMG reading,9 or an isokinetic exertion21 have been employed in occupational, low-velocity or gait applications, however, they have not been used in high-velocity muscle actions and thus will not be discussed further. For a more comprehensive review of the efficacies of these methods as normalization modalities, the reader is referred to Burden.15

Normalization using an MVIC has provided representative measures of muscle activation during clinical exercises including low-velocity gait,25 isotonic elbow flexions5 and isokinetic exercises53 and in some submaximal dynamic tasks (running/steady-state cycling) for some muscles, and thus its efficacy may be task/intensity and muscle dependent.27,52 However, in activities that require powerful high-velocity muscle actions (sprinting, cutting, jumping, cycling), EMG amplitudes greater than the supposed isometric maximum denominator have been generated.23,24,27,45,53 An MVIC necessitates the subject to hold a maximal load or exert a maximal force against a fixed load. This indicates that slower motor units with longer motor unit action potentials will remain, while the fast twitch motor units will drop out as evidenced by neural supplementation and magnetic resonance imaging studies.39,54,55 Thus a reduced contribution of the fast twitch fibers will result in force levels reducing after initial generation due to factors such as motivation, exhaustion of neurotransmitter stores, excitation contraction coupling, which may influence the EMG signal and subsequent normalization denominator.36 Generating an isometric maximum utilizing an explosive exertion may generate high levels of EMG. Explosive isometrics as proposed by Siff56 may be an alternate method to use to generate an EMG normalization value. Previous research has shown explosive mid-thigh isometric exertions to correlate well with sprint cycling performance and jumping.57 No research comparing the EMG generated from explosive isometric exertions compared with conventional high-velocity exercises currently exists.

MVIC normalization procedures are performed voluntarily and yet most high-velocity movements are performed involuntarily (ie, absorbance of force from a landing or sprint ground contact) and are done out of necessity to perform the movement successfully and reduce the chance of injury.47,58 Any investigation that relies on maximal human effort is subject to variability due to psychological and physiological factors that have been shown to increase inconsistency in maximal voluntary efforts levels.59,60 Previous research comparing EMG from MVIC and maximal 20 m sprints and maximal effort squat jumps has shown significantly less EMG activity and reduced intrasubject reliability in an MVIC compared with the dynamic tasks.24 Furthermore, it is the opinion of the authors that performing MVICs is generally an unfamiliar movement pattern for many subjects. Isometric movements are not frequently performed in sports which also require high-velocity power actions; thus there will be a degree of unfamiliarity with performing an isometric maximum. This unfamiliarity would contribute to a 20–30% reduction in the “maximum” contraction compared with an MVIC performed following training.61

The peak or mean EMG amplitude generated within the task has been used frequently to normalize EMGs generated from high-velocity muscle actions.18,42,62,63 Peak and mean dynamic normalization requires no additional
testing and eliminates the problems associated with selecting a reference muscle action, making this an attractive normalization method. Peak and mean dynamic electromyography normalization is mainly used to improve the interindividual variability of EMG and thus provide a template of activation during a task. Peak dynamic normalization has been used frequently in high-velocity activity to assess physical power drop-off over the course of a trial or to look at submaximal exertions. However, peak and mean dynamic normalization offers no information on the relative activation of the muscle, and is unable to demonstrate intra-individual changes in muscle activation or differentiate between injured and uninjured limbs. Therefore, peak and mean dynamic normalization is not recommended for electromyography normalization in high-velocity muscle actions.

**Basis of EMG Normalization Method Selection**

The decision on which normalization procedure to use may be linked to the aim of the study, the health and experience of the subject and the muscle tested. A raw EMG is often discarded, as true changes may be questionable due to the previously mentioned intrinsic and extrinsic factors. If assessing the effectiveness of any test or technique that is used to detect differences within (or between) subjects on separate occasions, then a reliability approach to normalization selection is likely to be adopted to reduce this variability. Intra-individual variability aims to compare the stability of the EMG between trials or days. Inter-individual variability is used to compare EMG amplitudes between subjects, and thus create a template of activity, such as stride in sprinting. Knutson et al. and Yang and Winter advocated adopting a intra-individual variability approach to normalization method selection because reliable data are required to definitively identify any intervention-based changes and considered reliable sample data to be more indicative of the population tested. One problem of adopting a reliability approach to normalization method selection is that it may not provide information on the level of muscle activation occurring in a task and can reduce the natural biological variability within a group. However, current studies using electromyography during physical power-based activities, while not stating why they normalized their data, have performed a normalization process and attempted to provide a template of muscle activity or identify changes in muscle activation for a given task.

To enable comparisons of relative muscle activation during a task or to compare between muscles and trials, the EMG would be of most use if it was presented in reference to the maximum activation of that muscle. This relative activation is of particular importance in assessing optimum exercises for muscles groups or assessing the relative intensity of physical power-based exercises and comparing the demands on the muscle during high-intensity activities. To express relative activation, it is intimated that the normalization method elicit an EMG of greater amplitude than the task. However, producing the maximum activation of a muscle is difficult. No studies to date have been able to assess the maximum level of an EMG from a muscle without the use of electrostimulation. A majority of researchers believe that maximal muscle activation is not possible through voluntary muscle actions, with Gandevia and McKenzie finding that healthy adults achieve maximal voluntary muscle activation in only about 25% of all maximal trials. The difficulties in assessing a true maximum make it more important to ensure the normalization method comes from an action with similar neural input. This is to ensure that motor units are recruited similar to those used in the action under investigation. This is particularly important in dynamic high-velocity-based actions where fast twitch muscle fibers only contribute over a certain level of force and velocity of movement. Buckthorpe et al. normalized explosive isometric knee contractions to the maximal compound muscle action potential by looking at the peak M-wave following supramaximal stimulation. This normalization method produced EMG values much in excess of the voluntary activation generated from maximal isometric efforts. The discomfort associated with supramaximal stimulation may preclude this method from being standard practice. More research is recommended into the relationship between M-wave normalization and voluntary exertions, to prevent patient discomfort.

While no formal method of validating a normalization procedure has been offered, previous research has assessed the validity of proposed EMG normalization methods via a reliability/variability analysis of the EMG values to be used as a denominator in the normalization equation. A variable denominator may cause unwarranted variability in the dynamic task being normalized thus giving a false positive as has been suggested previously. EMG activity from isometric muscle actions are inherently unreliable for triceps surae, tibialis anterior, and quadriceps muscle groups which further questions their use as a normalization method for high-velocity muscle actions. Validity can also be assessed by ensuring that the normalization process reflects the change in maximum neural drive. This gives further plausibility to the nonuse of an MVIC in high-velocity task EMG normalization.

**Normalization for High-Velocity Muscle Actions**

When normalizing high-velocity muscle actions, there has been an increased use of reference EMGs derived from dynamic muscle actions that are similar to the task. Although the validity of these methods has yet to be fully established, investigating new normalization methods shows a move toward the use of electromyography normalization values from muscle actions specific
to the task under assessment. Despite the problems associated with normalization methods that use MVIC or peak dynamic methods from high-velocity muscle actions they continue to be used to normalize EMG data as shown in recent publications. The remainder of this review will provide insight into the normalization methods used within high-velocity running and sprint cycling to reduce the impact of the aforementioned problems.

### Normalization for High-Velocity Running

Sprinting is prevalent in many sports and is often an essential component to performance success, particularly in sports such as basketball, baseball, hockey and soccer. Within field hockey, sprinting can account for up to 30% of competition time. From 2000 to 2011, 80 research papers relating to sprinting and EMG have been published. Of these 80 studies, 28 of these have looked at sprinting at speeds above 5.5 m/s and assessed lower leg temporal electromyograms. Of the 28 studies, only 8 have used a normalization process to assist in answering each paper’s aim. Table 1 shows these 8 studies published from 2000 to 2011 and the normalization methods used.

The studies presented in Table 1 indicate that from 2000 to 2011 there was a diversity of EMG normalization processes employed. The papers of Ball and Scurr and Albertus-Kajee attempted to identify the optimal normalization process for high-velocity muscle actions and used a range of methods on this basis. Ball and Scurr showed that MVIC normalization of triceps surae EMG during a 20 m sprint demonstrated poor intraindividual variability both between days and between weeks, which may be related to the poor intraindividual variability of the absolute maximum voluntary isometric EMG itself (CV: 12.6–24.7%). Liebenberg and Kyrolainen’s studies both used an MVIC and both found values far in excess of 100%, which queries how relevant the normalization values are to express relative activation. At maximal speed, Kyrolainen found medial gastrocnemius muscle activation levels of 230% when normalized to an MVIC in the stance phase of sprinting. The origin of these greater EMG amplitudes may lie in the necessity to exert high forces over short durations, thus recruiting a greater portion of fast twitch fibers. The studies that used normalization did so to produce a template of activity for that particular task and no between muscle comparisons were made. The continued use of isometric MVC in sprinting studies highlights a need to further investigate a normalization procedure effective for this activity.

### Normalization for Sprint Cycling

In his review on EMG in cycling, Hug stated that there is no clear consensus on the optimal normalization method for EMG use in cycling, and investigation into such methods will be important for the future interpretation of EMG signal. For cycling a mixed approach to EMG normalization methods has been adopted. Papers have used both peak dynamic and mean dynamic normalization successfully when looking at assessing patterns of activity in pedal strokes or if considering physical power drop-off as can occur in a maximal sprint trial. However, as Hug stated, these methods do not provide information on the muscle activity required during pedaling. From 2000 to 2011, 199 research papers relating to fast/maximal/sprint cycling and EMG have been published.

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**Table 1 Summary of EMG literature (2000 to 2011) relating to sprint running activities and the normalization method implemented**

<table>
<thead>
<tr>
<th>Authors</th>
<th>Event</th>
<th>Muscles Assessed</th>
<th>Normalization Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albertus-Kajee et al</td>
<td>Maximum 20 m sprint and 70% of max treadmill speed</td>
<td>VM, BF, MG, RF, VL, LG</td>
<td>MVIC, 20 m sprint (peak), 70% treadmill running speed</td>
</tr>
<tr>
<td>Ball and Scurr</td>
<td>Maximum 20 m sprint</td>
<td>MG, LG, SOL</td>
<td>MVIC / SUB MVIC / BW (isometric / isokinetic / isotonic), squat jump, peak dynamic</td>
</tr>
<tr>
<td>Liebenberg, Scharf, et al</td>
<td>100%, 115%, and 125% of preferred speed</td>
<td>RF, BF, TA, GA</td>
<td>Maximum value from 100% preferred speed</td>
</tr>
<tr>
<td>Chumanov, Heiderscheit, et al</td>
<td>Treadmill sprint &gt; 7.5 m·s⁻¹</td>
<td>BF / ST / SM</td>
<td>Peak dynamic</td>
</tr>
<tr>
<td>Higashihara, Ono, et al</td>
<td>50 / 75 / 85 / 95% max running speed</td>
<td>BF, ST</td>
<td>Peak dynamic</td>
</tr>
<tr>
<td>Kyrolainen, Avela, et al</td>
<td>Max sprinting</td>
<td>MG, VL, BF, RF, GM, TA</td>
<td>MVIC</td>
</tr>
<tr>
<td>Boyer, Nigg, et al</td>
<td>5.5 m·s⁻¹</td>
<td>TA, GM, RF, BF</td>
<td>Mean</td>
</tr>
<tr>
<td>Kyrolainen, Belli, et al</td>
<td>Mean maximal speed 8.31 m·s⁻¹</td>
<td>GM, VL, BE MG, TA</td>
<td>Peak dynamic</td>
</tr>
</tbody>
</table>

Note: VM, vastus medialis; VL, vastus lateralis; RF, rectus femoris; BF, biceps femoris; ST, semitendinosus; SM, semimembranosus; GM, gluteus maximus; MG, medial gastrocnemius; LG, lateral gastrocnemius; SO, soleus; TA, tibialis anterior; MVIC, maximum voluntary isometric contraction.
Of these 199 studies, 21 have looked at all out sprinting and assessed lower leg temporal electromyograms. Of the 21 papers only 11 have required to use a normalization process to assist in answering each paper’s aim. Table 2 show these 11 papers published from 2000 to 2011 and the normalization methods used.

The studies shown in Table 2 indicate diversity between normalization using the peak of the first sprint in a repeated sprint battery or an MVIC. In support of more specific electromyography normalization methods, Rouffet and Hautier\(^\text{27}\) and Fernandez-Pena et al\(^\text{74}\) reported that current isometric normalization methods did not reflect the maximum neural drive needed during cycling. Rama\(^\text{48}\) successfully used an EMG from a separate maximum Wingate test as the normalization value for subsequent cycling tests. To establish the electromyography normalization value, Rouffet and Hautier\(^\text{27}\) used a torque/velocity cycling test whereby the subject performed maximum sprints against friction loads on an ergometer. This built upon work by Hunter et al,\(^\text{53}\) who used an isometric EMG obtained with the foot on the pedal. Rouffet and Hautier\(^\text{27}\) found both reduced interindividual EMG variability compared with an off-bike maximum isometric muscle action for the gluteus maximus, soleus and vastus lateralis, and comparatively greater EMG amplitudes from these same muscles. However, the reverse trend was shown for the biceps femoris and rectus femoris with the isometric maximum showing reduced interindividual variability and greater EMG amplitudes. The differences were related to the differing roles of the muscles within a cycling task and indicate that optimal normalization method may vary between muscles. Despite differences in variability, the authors recommended a new normalization method, in which the extraction of the maximum EMG was similar to the neural drive that occurred during the submaximal cycling task and was regulated by the same afferent feedback. Continuing this work, Fernandez-Pena et al\(^\text{74}\) used a maximum isokinetic protocol on cycle ergometer to establish the EMG normalization value. This involved subjects pedaling on an ergometer up to a set cadence and then resistance was automatically and proportionally increased when the subject tried to overcome it. They concluded that the specificity of the protocol permitted high intraindividual EMG variability between trials for the vastus lateralis (4.46 CV %), gastrocnemius lateralis (6.85 CV %) and the tibialis anterior (8.70 CV %). Interestingly, the intraindividual variability between trials was also low for the biceps femoris (7.32 CV %), which contradicts Roufett and Hautier’s\(^\text{27}\) work. Fernandez-Pena et al\(^\text{74}\) concluded the test to be valid on the basis of increases in intensity being mirrored by similar increases in EMG activation; however, they did not compare their proposed method to maximum isometric muscle action normalization.

Moving away from specialist isokinetic equipment to elicit a normalization value, Albertus-Kajee\(^\text{80}\) compared MVC, a maximal dynamic (10 s cycle sprint) and submaximal dynamic (mean EMG value over a 5 minute exertion at 70% peak power output) normalization method on a cycling exercise to exhaustion. Although no actual normalization values were presented, they did conclude that the normalization methods that replicated the movement (maximal dynamic and submaximal dynamic cycling) were more repeatable and reliable than a conventional MVIC normalization procedure. Furthermore, Albertus-Kajee\(^\text{80}\) did not use specialist equipment, thus

### Table 2  Summary of EMG literature (2000 to 2011) relating to sprint cycling activities and the normalization method implemented

<table>
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<th>Muscles Assessed</th>
<th>Normalization Method</th>
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<tbody>
<tr>
<td>Albertus-Kajee, Tucker, et al(^\text{80})</td>
<td>Maximum 10 s sprint and 70% peak power output</td>
<td>VM, BF, MG, RF, VL, LG</td>
<td>Isometric MVC, maximum 20 m sprint, and 70% peak power output</td>
</tr>
<tr>
<td>Smith and Billaut(^\text{81})</td>
<td>10 × 10 s sprints</td>
<td>VL, VM</td>
<td>Peak of first sprint</td>
</tr>
<tr>
<td>Mendez-Villanueva, Hamer, et al(^\text{84})</td>
<td>10 × 6 s sprints</td>
<td>VL</td>
<td>Peak of first sprint</td>
</tr>
<tr>
<td>Billaut and Basset(^\text{87})</td>
<td>10 × 6 s sprints</td>
<td>VL</td>
<td>MVIC</td>
</tr>
<tr>
<td>Racinais, Bishop, et al(^\text{88})</td>
<td>10 × 6 s sprints</td>
<td>VL, BF</td>
<td>Peak of first sprint</td>
</tr>
<tr>
<td>Matsuura, Ogata, et al(^\text{89})</td>
<td>10 × 10 s sprints</td>
<td>VL, RF</td>
<td>Peak of first sprint</td>
</tr>
<tr>
<td>Bundle, Ernst, et al(^\text{90})</td>
<td>Repeat all out sprints</td>
<td>VL</td>
<td>Mean Peak of first burst of activity in the first sprint.</td>
</tr>
<tr>
<td>Billaut, Basset, et al(^\text{2})</td>
<td>10 × 6 s cycling sprints</td>
<td>VL, VM</td>
<td>MVIC</td>
</tr>
<tr>
<td>Billaut, Basset, et al(^\text{26})</td>
<td>10 × 6 s cycling sprints</td>
<td>VL, BF</td>
<td>Peak of first sprint</td>
</tr>
<tr>
<td>Kay, Marino, et al(^\text{93})</td>
<td>6 × 1 min all out sprints within a 60 min submaximum cycle</td>
<td>RF</td>
<td>Peak of first sprint</td>
</tr>
<tr>
<td>Hautier, Arsac, et al(^\text{91})</td>
<td>15 × 5 s sprints</td>
<td>VL, RF, GM, LG, MG</td>
<td>MVIC</td>
</tr>
</tbody>
</table>

Note. VM, vastus medialis; VL, vastus lateralis; RF, rectus femoris; BF, biceps femoris; GM, gluteus maximus; MG, medial gastrocnemius; LG, lateral gastrocnemius; MVIC, maximum voluntary isometric contraction.
making these forms of normalization easy to conduct and collect.

**Summary**

Normalization is an important component of the electromyography process to enable valid and reliable interpretations and comparisons of muscle activity. Investigations into electromyography normalization methods are complicated by the abundance of extrinsic and intrinsic factors and the variability between muscles. However, this complexity should not lead to the abandonment of normalization or the continued use of inappropriate procedures, as the selection of the optimum procedure can be the foundation for valid and reliable EMG interpretation. Previously investigated methods of normalization (isometric, peak dynamic task) could be considered unsuitable for interpreting EMG activity from high-velocity muscle actions; however, this is muscle and task dependent. The current methods’ lack of ability to clearly represent relative muscle activation suggests that alternative methods are required. Alternative methods focusing on muscle actions from tasks with similar drive are currently being investigated within cycling and running. Electromyography investigators should aim to identify normalization methods that reduce intra-individual variability and are a representative measure of muscle activation. It is imperative that more work is done to validate the new methods of normalization before they are adopted and so that a quorum supports moving away from ineffective current normalization methods.

**Future Directions in High-Velocity Normalization**

Investigations into alternative electromyography normalization methods are scarce and have centered around clinical populations where current methods may be inappropriate or compromised. Electromyography values from passive movements or an interpolated twitch technique have been investigated for electromyography normalization for injured patients or patients with neurological dysfunction and more recently for explosive isometric contractions. Using the suggestions of Siff, an explosive isometric action may provide an appropriate normalized value for high-velocity muscle actions. Marras et al. successfully implemented an extrapolation electromyography normalization method based on submaximum EMG activity and moment data for trunk muscles during low-velocity exertions. These methods represent a move away from voluntary muscle action normalization, reducing the psychological factors that can affect signal variability while providing a suitable denominator. Further assessment of the efficacy of these methods for high-velocity muscle actions is needed.

**Guidelines for Electromyography Normalization for High-Velocity Muscle Actions**

- The normalization method should involve an action similar to the task under investigation—for example, in cycling, a maximum-effort resisted cycle rotation when on the bike, or, in sprinting and jumping, a maximum-effort 20 m sprint. This is due to the EMG value being derived under the same neural conditions as the task.
- Maximum voluntary isometric EMG normalization procedures should be used with caution owing to their inability to reflect neural drive in high-velocity muscle action normalization. This procedure may be suitable for certain muscles that are not maximally activated during a high-velocity task.
- Any normalization methods should be reported alongside an intrasubject variability measure of the normalization method itself.
- New electromyography normalization methods should demonstrate good inter/intrareliability and normalized amplitude values of less than 100%.
- Optimal EMG normalization methods may differ for each muscle. It is advised to adopt a single method and term it a reference muscle action.
- Normalization methods should use movements that are familiar and where possible require maximal involuntary effort.

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66. Fernandez-Pena E, Lucertini F, Ditroilo M. A maximal isokinetic pedalling exercise for EMG normalization in


