REGIONAL MUSCLE ACTIVATION OF THE BICEPS FEMORIS

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The purpose of this study was to examine regional BFlh (M. biceps femoris long head) activation during isometric knee flexion. Using an isokinetic device and high-density EMG (electro-myography), 11 males performed contractions at all combinations of short, medium and long MTU (muscle-tendon-unit) lengths and three torque levels ($30\%_{MVC}$, $60\%_{MVC}$, $90\%_{MVC}$ (maximum voluntary contraction)). Distal BFlh exhibited significantly higher activation at $60\%_{MVC}$ and $90\%_{MVC}$ than proximal, indicating intensity-dependent heterogeneity. No effects of muscle length on muscle activation were found. Practitioners should be mindful of potential intramuscular variations in biarticular muscles during different contraction circumstances with potential implications for hamstring injury risk assessment and exercise selection.

KEYWORDS: hamstrings, muscle injury, regional muscle activation, high-density EMG

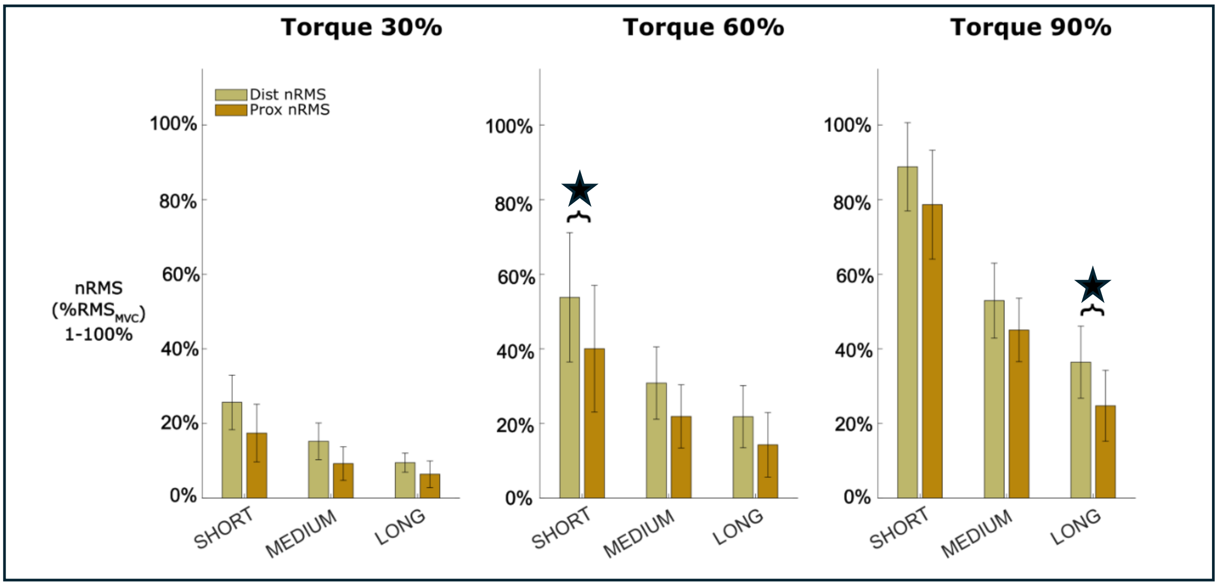
INTRODUCTION: Movement of the musculoskeletal system in sports usually has one desired outcome – perform an action in the sport-specific task. Deviations in planning or movement of the musculoskeletal system, be it through internal or external factors, often result in undesirable outcomes as sport-specific or physical performance can decrease, or in the worst cases injuries happen. Hamstring injuries are among the most common in field sports, and the most common muscle injury in football (Maniar et al., 2023). Despite extensive research, hamstring injury incidence and time-loss from these injuries increased in the last 20 years, and hamstring injury share of all injuries in football doubled (Ekstrand et al., 2022). Among hamstring injuries, the M. biceps femoris long head (BFlh) is the most injured muscle, with the proximal musculo-tendinous junction being the most affected location (Crema et al., 2016).
Previous work on BFlh has focused on one region representative for the whole muscle in regards to muscle activation but a recent article suggests a regional activation hypothesis in biarticular muscles (Watanabe et al., 2021). As muscle activation is directly linked to the contraction intensity of a muscle during a movement due to the excitation-contraction-coupling (Calderon, Bulaños & Caputo, 2014), heterogeneity of muscle activation has implications for load distribution within a muscle. Taking the excitation-contraction-coupling into consideration, heterogeneously activated muscles could be more susceptible to injuries.
Investigating intramuscular regional activation patterns within BFlh can have implications for research into risk factors of the hamstrings, and more specifically BFlh injuries, but also for prevention and rehabilitation methods such as exercise selection. While specific exercises are widely used to combat hamstring injuries, it is unclear if and how these exercises affect injury risk (Presland et al., 2018). Thus this study's goal was to describe differences in proximal and distal spatial activation within the BFlh during isometric knee flexion contractions, and how muscle-tendon-unit (MTU) length and contraction intensity affect the regional BFlh activation during the contraction.

METHODS: To investigate regional differences in muscle activation in the M. biceps femoris long head 11 recreationally active males (mean age 28.6 years, 23-35 years) were recruited. Exclusion criterium was a lower extremity injury within the past year. Knee flexion torque and BFlh muscle activation were recorded via the Isomed2000 (D. & R. Ferstl, Isomed2000, Hemau, Germany) and a 64-channel HDEMG system (OT Bioelettronica, Sessantaquattro, Torino, Italy), both sampled at 2000 Hz. After a standardized warm-up, subjects performed

isometric knee flexion contractions in a seated position on the Isomed2000. The knee joint was held constant at 45° flexion, while the included hip joint angles were chosen to represent muscle-tendon-unit (MTU) lengths 0° (short), 45° (medium) and 90° (long) flexion. The joint angles were controlled via Isomed2000 goniometers. One MVC measurement was conducted in the short MTU length for each subject. In each MTU length subjects performed ramp-up contractions to $30\%_{MVC}$, $60\%_{MVC}$ and $90\%_{MVC}$, to ensure constant Isomed-measured torque across MTU lengths for each torque level.
Two 32-channel electrode matrices (8x4) were applied to the biceps femoris at 35% (proximal electrode matrix) and 65% (distal electrode matrix) of BFlh MTU length. BFlh MTU length was defined as the distance between the Tuber ischiadicum (0%) and the fibula head (100%). The reference electrode was fixed to the ipsilateral ankle. Monopolar HD-EMG signals (2x32 channels) digitized by a 16-bit analog-to-digital converter (OT Bioelettronica, Sessantaquattro, Torino, Italy). The recorded monopolar signals were bandpass filtered offline (10.5–500 Hz) and transferred to analysis software (MATLAB R2023b, MathWorks GK, Natick, MA). Bipolar HDEMG signals (resulting in 28 single-differential channels) along the columns were obtained for both 32 electrode matrices. Electrode matrices were checked for noisy channels via outlier detection (Malesevic et al., 2021) and outlier-channels were interpolated using the two nearest channels within the same column or adjacent column. Root mean square values for bipolar HDEMG signals and a moving mean for Isomed torque, both with a one-second window, were normalized to each subject's MVC HDEMG amplitude and Isomed torque, respectively. For analysis the one-second window with the least difference to the target torque was selected. Subsequently heatmaps were generated, displaying color-coded activation amplitude of each bipolar signal, corresponding to their position on the electrode matrix. To compare the proximal and distal HDEMG matrices the normalized RMS (nRMS) values of the matrices for each region were averaged, to gain one value representative of the muscle activation in the respective region. HDEMG was chosen to cover a greater area than possible with conventional EMG. To investigate the influence of MTU length, torque level and muscle region (proximal/distal) on nRMS a three-way repeated measures ANOVA was conducted with muscle region, MTU length and torque level as the within-subject factors. Due to sphericity violations the alpha-level for significance of 0.05 was Greenhouse-Geisser-corrected.

RESULTS: Mean MVC torque across subjects was 83.15 Nm (± 20.27 Nm, 43.41 Nm - 119.47 Nm). Mean torque across lengths was 28.04% (±2.91%) for $30\%_{MVC}$, 59.18% (±5.58%) for $60\%_{MVC}$ and 88.66% (±6.43%) for $90\%_{MVC}$. Mean values for nRMS for all combinations of MTU lengths and torque levels are visualized in Fig. 1.
The three-way repeated measures ANOVA showed no significant three-way interactions between muscle regions, MTU length and torque level regarding amplitude of muscle activation but a significant two-way interaction between muscle region and torque level ($F = 6.179$, $p = 0.021$) was found for nRMS. The post-hoc test revealed significantly higher activation in the distal region in $60\%_{MVC}$ ($p = 0.001$, Cohen's $d = -1.014$) and $90\%_{MVC}$ ($p = 0.001$, Cohen's $d = -0.996$) torque levels. Mean nRMS across torque levels is shown in Fig. 2.
No significant interaction between muscle regions and lengths was found in regards to nRMS amplitude. Significant simple main effects for muscle regions were found in the conditions short-$60\%_{MVC}$ ($F = 7.531$, $p = 0.021$) and long-$90\%_{MVC}$ ($F = 5.271$, $p = 0.045$), showing significantly higher muscle activation in the distal region.

DISCUSSION: The study's goal was to investigate regional differences in muscle activation in the BFlh during isometric knee flexion contractions in different MTU lengths and contraction intensities. The key findings are that muscle activation differed between proximal and distal BFlh regions with the distal region showing higher muscle activation in the $60\%_{MVC}$ and $90\%_{MVC}$ but not $30\%_{MVC}$ torque levels across MTU lengths. Previously regional activation within BFlh has been described, but no meaningful differences between regions in two different movement tasks were found (Watanabe, Kouzaki & Moritani, 2016). In light of the results of a study investigating regional muscle activation within the M. rectus femoris in either hip flexion or knee extension, the authors suggested a higher amplitude of regional muscle activation in the region closest to the target joint in biarticular muscles (Watanabe et al., 2021). This pattern was also observed in present study. While only statistically significant differences for the short MTU length at $60\%_{MVC}$ and long MTU length at $90\%_{MVC}$ were found, mean values across subjects



for normalized RMS were higher in every condition in the distal region than in the proximal region.

Figure 1. Normalized RMS for proximal and distal M. biceps femoris long head regions for $30\%_{MVC}$, $60\%_{MVC}$ and $90\%_{MVC}$ torque levels across MTU lengths during isometric knee flexion. ★ Indicates significant differences between proximal and distal muscle regions for the corresponding condition.

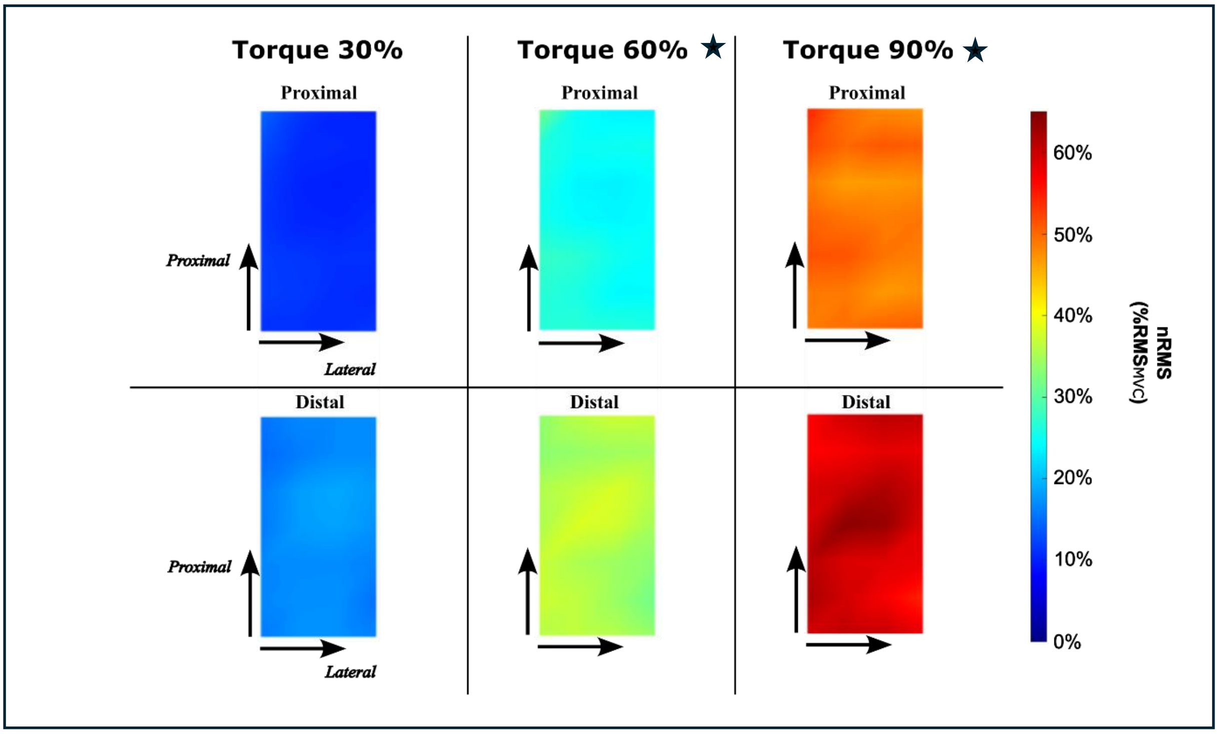


Figure 2. Normalized RMS (nRMS) heatmaps for proximal (top) and distal (bottom) M. biceps femoris long head regions for $30\%_{MVC}$, $60\%_{MVC}$ and $90\%_{MVC}$ torque levels across MTU lengths during isometric knee flexion. nRMS is displayed as color-coded in the location of the corresponding bipolar HDEMG channel. ★ Indicates significant differences between proximal and distal muscle regions for the corresponding torque level.

Summarizing key findings for this sample of 11 subjects the contraction intensity was shown to influence regional BFlh activation strategies, with more heterogenous activation between

distal and proximal activations at higher intensity levels in isometric knee flexion contractions. $60\%_{MVC}$ showed a higher heterogeneity than $90\%_{MVC}$ torque levels, suggesting that this relationship is not linear.
In this sample, no effect of MTU length on the differences between proximal and distal muscle activation was found.
With increasing hip angle a decrease in required muscle activation was observed for the same torque levels (30%, 60% & 90%). This interaction between torque, hip angle and muscle activation could suggest that the BFlh operates on the ascending limb of the force-length-curve in the present contraction circumstances, but further research directly measuring muscle force and length are needed to investigate this.
The present study is limited by the number of subjects, thus future research should aim to corroborate the present results with a higher number of subjects. Accordingly the ANOVA results were corrected for sphericity violations. Electrode placement was conducted without ultrasound guidance. Due to inter-individual anatomical and morphological differences this can result in different electrode placements across subjects with respect to individual BFlh anatomical features. Further it is important to note that contractions in different MTU lengths at the same torque level are not equally demanding for the BFlh, since all trials are normalized to the MVC measurement in the short position.

CONCLUSION: In summary, the findings suggest that the distal region of BFlh shows higher normalized muscle activation during isometric knee flexion than the proximal region. The level of contraction intensity seems to have an effect on the heterogeneity of muscle activation within BFlh, with some intensities resulting in more pronounced regional differences in activation.
While the present data suggests that the BFlh operates on the ascending limb of the force-length-relationship, more targeted research with better suited designs for the influence of MTU length are needed. Practitioners should be aware that it is likely that, in biarticular muscles, different contraction circumstances can result in different intramuscular regional activation and thus different regional intramuscular loading and adaptation. The findings highlight the importance of muscle activation patterns in injury prevention and rehabilitation and should lead to further research on regional BFlh activation during demanding actions (e.g. sprinting) and exercises to inform hamstring injury prevention and rehabilitation strategies.

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