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Electromyographical Differences Between the Hyperextension and Reverse-Hyperextension

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Abstract

Cuthbert, M, Ripley, NJ, Suchomel, TJ, Alejo, R, McMahon, JJ, and Comfort, P. Electromyographical differences between the hyperextension and reverse-hyperextension. *J Strength Cond Res* 35(6): 1477–1483, 2021—The aims of this study were to compare muscle activation of the erector spinae (ES), gluteus maximus (GMax), and biceps femoris (BF) during the hyperextension (HE) and reverse-HE (RHE) exercises. Ten subjects (age, 23 ± 4 years; height, 175.9 ± 6.9 cm; mass, 75.2 ± 9.7 kg) had electromyography (EMG) electrodes placed on the ES, GMax, and BF muscles in accordance with SENIAM (Surface EMG for Non-Invasive Assessment of Muscles) guidelines. Subjects performed 3 maximum voluntary isometric contraction trials of lumbar extension and hip extension using a handheld and isokinetic dynamometer, respectively, to normalize the EMG during the HE and RHE exercises. Three repetitions of each exercise were executed in a randomized order. High reliability (intraclass correlation coefficient ≥0.925) was observed with low variability (coefficient of variation [CV] $<$ 10%) in all but the GMax during the extension phase of the HE (CV = 10.64%). During the extension and flexion phases, the RHE exhibited significantly greater ($p \leq 0.024$; 34.1–70.7% difference) peak EMG compared with the HE in all muscles tested. Similarly, the RHE resulted in significantly greater mean EMG compared with the HE ($p \leq 0.036$; 28.2–65.0% difference) in all muscles except the BF during the flexion phase ($p = 9.960$). Therefore, the RHE could be considered as a higher-intensity exercise for the posterior chain muscles compared with the HE, potentially eliciting greater increases in strength of the posterior chain muscles.

Key Words: posterior chain, erectors, hamstrings, gluteals, EMG

Introduction

The primary hip extensor muscles (gluteals and hamstrings) form part of the posterior chain and are integral for force production to accelerate an individual's center of mass in a given direction, when performing athletic tasks (2,4). Therefore, hip extension has been highlighted as a key factor for sprinting (particularly from the stance to toe-off phase) (1,2,4,18,29,34), jumping (1,25,34), and lateral movements such as side shuffles (1,31,34). The hip extensors are also essential for rapid force production during many deceleration actions as both a mechanism for injury risk reduction and to increase performance of such tasks. An example of the hamstrings, being a biarticular muscle, is to generate high forces, rapidly, to decelerate the shank during the late swing phase of the gait cycle, particularly in high-speed running and sprinting (15,16,18), which is the point of the cycle at which hamstring strains are suggested to occur (5,7,9,20,32). Other examples include rapid deceleration during jump landings and during change of direction tasks, whereby the hip extensors are also understood to attenuate ground reaction forces around the knee, which contribute to change of direction performance and improved landing mechanics (12,26). Appropriate development of the trunk musculature may also contribute to positive enhancement of performance, particularly during change of direction tasks, via the efficient transfer of force generated from the lower body through the whole kinetic chain (11,14,27). Moreover, trunk musculature would also aid in lumbopelvic control, which has been identified as being particularly important to help avoid hamstring injury occurrence in high-speed running (30). It is therefore important to develop the posterior chain musculature, particularly in sports that involve both rapid accelerations and decelerations, and high-speed running, to maximize performance and potentially reduce the risk of injury.

Until recently (21), there has been limited investigation into both the hyperextension (HE), which is sometimes referred to as 90° hip extension, and reverse-HE (RHE), despite these exercises anecdotally being used by competitive athletes. The RHE requires athletes to hang their lower body in a prone position from a padded platform in parallel to a pendulum whereby the feet are attached and the athletes can extend the hip while maintaining an extended knee, pulling their lower limbs up from approximately 90° hip flexion to approximately 0° hip flexion (Figure 1). Within the aforementioned study (21), biomechanical differences, including muscle activation and both kinetic and kinematic variables, were calculated across 10 repetitions of both HE and RHE, both of which can typically be executed using the same piece of equipment. No significant differences were present between HE and RHE in peak and mean activation of the erector spinae (ES), gluteus

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maximus (GMax), and biceps femoris (BF). Range of motion (ROM) around the trunk and pelvis was significantly greater during HE, whereas ROM around the trunk and thigh are greater during RHE, which can be intuitively explained as whether the lower or upper body is held in a fixed position during the HE and RHE exercises, respectively. The significantly greater ROM observed around the trunk and pelvis could be a contraindication, particularly if that ROM is occurring as a result of spinal flexion because this may be putting undue pressure on the spine while also contradicting the desired bracing action around the trunk usually expected during resistance exercise. Peak and mean moments around the lower back were also significantly greater during the RHE. The difference in lower back moment could have simply been down to the change in lever length, with the majority of weight during the RHE being placed at the end of a pendulum, compared with the HE whereby the additional mass was held to their torso, resulting in a shorter lever. The only differences in muscle activation were the integrated electromyography (EMG), with significantly greater results in the GMax and BF during the HE. An explanation for the significant differences in integrated EMG could be the result of the ballistic nature of the exercises performed. As mentioned, the tests were performed while subjects executed bouts of 10 repetitions, described as using a cadence of 1:1 (1 second up and 1 second down). Keeping a 1:1 cadence within the HE would have meant constant tension and therefore greater time under tension within the muscles assessed, increasing integrated EMG. In contrast, during the RHE, there may have been some short period of reduced activity as the swinging of the pendulum caught up with the action of the lower body, particularly if a large amount of force (as demonstrated by the significantly greater moments within this exercise) is produced rapidly during the initial ROM, this creates momentum that could increase the reduction in activity as certain points of the movement. Although a ballistic approach can be viewed as ecologically valid, it is also important to understand what occurs during single repetitions, identifying both the "concentric" and "eccentric," or extension and flexion phases to know the most appropriate application of the exercise.

The aims of this study were, therefore, to assess differences in surface EMG of the ES, GMax, and BF bilaterally during the extension and flexion phases of HE and RHE. It was hypothesized that peak and mean EMG would be greater overall in the RHE compared with the HE due to there being a greater lever length.

Methods

Experimental Approach to the Problem

To compare differences in EMG, of the ES, GMax, and BF muscles, between the HE and RHE exercises, an observational cross-sectional design was implemented whereby subjects performed 3 repetitions of both exercises in a randomized order. Before this, each subject performed 3 maximum voluntary isometric contractions maximum voluntary isometric contractions (MVIC) during 2 different exercises (hip extension and back extension) to permit normalization of the EMG during the HE and RHE. Each exercise was divided into an extension and flexion phase, with a brief pause, when fully extended, to permit differentiation of the EMG signal between the 2 phases.

Subjects

Seven male and 3 female subjects (height, mass, and ages were all *SD*: age, 23 ± 4 years; height, 175.9 ± 6.9 cm; mass, 75.2 ± 9.7 kg; no subjects included in this study were <18 years of age) volunteered to participate in this investigation and provided written informed consent. All subjects had been resistance training recreationally for a minimum of 6 months before taking part in this investigation and were all familiar with the exercises. The study was approved by University of Salford institutional review board (HST1718-019).

Procedures

Electromyography. Each subject had EMG electrodes (Noraxon Dual EMG electrode; Noraxon U.S.A. Inc, Scottsdale, AZ) placed on their ES, GMax, and BF, in accordance with SENIAM (Surface EMG for Non-Invasive Assessment of Muscles) guidelines (13). A standardized protocol for the preparation of skin and application of electrodes was used to ensure stable contact and low skin impedance. This involved shaving of the skin, light abrasion, and cleansing using alcohol wipes. Self-adhesive dual snap surface silver/silver chloride (Ag/AgCL) bipolar electrodes (Noraxon Dual EMG electrode; Noraxon USA. Inc.), were placed upon the muscle bellies. The electrode placement was parallel with the orientation of muscle fibers, in accordance with SENIAM guidelines. Wireless EMG sensors (2B EMG Sensor; Noraxon USA. Inc.) were attached to the electrodes following correct placement, and a quality check was performed. Live EMG data were transmitted via the wireless sensor to a receiver (Desktop DTS Receiver; Noraxon USA. Inc.) connected to a portable laptop running myomuscle software (MR3 Myomuscle; Noraxon USA. Inc.). All EMG data were collected at 1,500 Hz.

Maximum Voluntary Isometric Contractions. Initially, subjects performed 2 MVICs, including lumbar extension and prone hip extension to normalize dynamic EMG values. The prone hip extension was assessed using an isokinetic dynamometer (IKD) (Biodex Multi-Joint System 4 Isokinetic Dynamometer, New York, NY), with trials exhibiting a peak force within ±10% of the previous trial accepted as a maximal effort, unless there was a progressive increase in peak force. Joint centers were positioned at the point of rotation of the IKD with the pad placed above the distal portion of Achilles tendon for the hip extension. Hip extension trials were performed with full knee

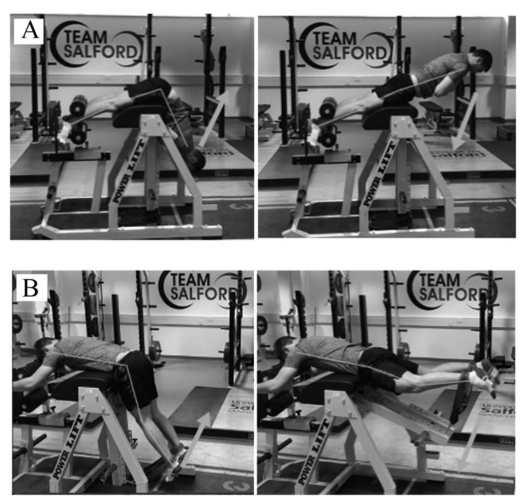

Figure 1. An illustration of the performance of the (A) hyperextension and (B) reverse-hyperextension.

Table 1

Comparison of peak and mean normalized electromyography between the hyperextension and reverse-hyperextension.

	Phase	Muscle	Exercise	Mean (±*SD*) (% MVIC)	ICC (95% CI)	CV%	% Difference	*p*	Hedges *g*	Power
Peak	Extension	Erector spinae	RHE	107.3 ± 37.9	0.969 (0.928–0.987)	3.14	46.8	0.012	1.01	0.90
			HE	73.1 ± 25.4	0.989 (0.973–0.996)	5.42				
		Gluteus maximus	RHE	49.3 ± 37.5	0.961 (0.910–0.984)	8.89	63.2	0.012	1.06	0.93
			HE	18.1 ± 13.1	0.958 (0.891–0.983)	10.64				
		Biceps femoris	RHE	58.8 ± 21.7	0.966 (0.906–0.986)	6.33	34.1	0.024	0.95	0.87
			HE	38.7 ± 18.6	0.969 (0.924–0.987)	7.40				
	Flexion	Erector spinae	RHE	101.6 ± 37.1	0.925 (0.830–0.968)	4.90	41.7	<0.001	1.22	0.97
			HE	59.2 ± 29.1	0.989 (0.973–0.996)	4.56				
		Gluteus maximus	RHE	52.6 ± 33.6	0.972 (0.933–0.988)	5.89	70.7	<0.001	1.44	0.99
			HE	15.4 ± 9.8	0.963 (0.911–0.985)	9.62				
		Biceps femoris	RHE	58.9 ± 21.3	0.974 (0.937–0.989)	4.63	36.7	0.024	1.04	0.92
			HE	37.3 ± 18.4	0.966 (0.917–0.986)	7.78				
Mean	Extension	Erector spinae	RHE	71.0 ± 30.5	0.975 (0.937–0.990)	5.15	38.1	<0.001	1.03	0.91
			HE	43.9 ± 18.3	0.941 (0.840–0.977)	6.06				
		Gluteus maximus	RHE	23.4 ± 15.8	0.973 (0.933–0.989)	9.06	65.0	<0.001	1.25	0.98
			HE	8.2 ± 4.5	0.943 (0.863–0.977)	8.71				
		Biceps femoris	RHE	39.7 ± 13.4	0.935 (0.844–0.974)	6.93	28.2	0.036	0.75	0.71
			HE	28.5 ± 15.1	0.942 (0.861–0.977)	10.35				
	Flexion	Erector spinae	RHE	51.8 ± 16.1	0.955 (0.890–0.982)	3.87	41.1	<0.001	1.47	1.00
			HE	30.5 ± 11.3	0.966 (0.916–0.986)	5.05				
		Gluteus maximus	RHE	18.6 ± 9.2	0.973 (0.933–0.989)	5.68	51.1	<0.001	1.15	0.96
			HE	9.1 ± 6.5	0.996 (0.989–0.998)	4.42				
		Biceps femoris	RHE	28.3 ± 23.3	0.975 (0.937–0.990)	6.73	20.8	9.960	0.30	0.22
			HE	22.4 ± 13.3	0.983 (0.957–0.993)	6.67				

RHE = reverse hyperextension; HE = hyperextension; MVIC = maximum voluntary isometric contraction; ICC = intraclass correlation coefficient; CI = confidence interval; CV = coefficient of variation.

extension. The ES MVIC was assessed during a prone back extension, using a handheld dynamometer placed between the scapulae and with an adjustable strap providing a constant immovable resistance, with the same ±10% threshold applied to ensure maximal effort.

Specific verbal cues were provided for each MVIC, as appropriate cueing has been highlighted to have a positive difference in the timing and magnitude of contraction in gluteal and hamstring activation, during a prone hip extension (22). The instructions of "raise your heel to the ceiling" and "raise your chest towards the ceiling" were used for hip extension and back extension, respectively. Subjects were also instructed to contract their muscle as hard and as fast as possible for each trial, to enable achieve peak force (3). Two minutes of rest was provided between each trial.

Exercise Performance. Subjects performed 3 repetitions of the HE and 3 repetitions of the RHE on a posterior chain developer (PowerLift, IA), in a randomized order whereby all repetitions of the HE was followed by the RHE or vice versa, with a 1-minute rest between repetitions. Subjects were instructed to remain as relaxed as possible before commencing the extension phase (Figure 1A and B), to pause at the end of this phase before being given a command to "flex" to commence the flexion phase (Figure 1A and B). Subjects were instructed to perform a cadence of 1 second for both the extension and flexion phases through a full range of motion, which was comparable between exercises. At the end of each repetition, subjects were asked to relax. Subjects being relaxed at the start of the extension phase and the end of the flexion permitted automated identification of the start and end of these phases, respectively, as described below. Reverse-HE trials, however, included a load attached to a swinging pendulum that was standardized to match the subject's upper-body weight, including the torso, head, and arms (62.9% of body mass), minus the weight of the pendulum arms and subjects legs (16.1% of body weight per leg) in accordance with the segmental model provided by Clauser et al. (8). This standardization of load allowed direct comparison between exercises.

Data Analysis. Analysis of EMG was performed using a bespoke Excel spreadsheet, calculating the mean and peak root-mean-squared values during each phase of each exercise with a moving average window of 200 milliseconds. The extension and flexion phases of the movement were identified as follows: onset and termination of movement, was assessed using a threshold of >2 *SD*s plus the mean of the EMG during a 1-second period of relaxation before and after movement, with the end of the extension and start of the flexion phases determined via a manual trigger during the exercise. Data were then expressed as a percentage of the peak EMG during the MVIC for both the peak and mean EMG during both the extension and flexion phases of the exercises.

Statistical Analyses

All data in this study data are presented as mean ± *SD*. Normality of all data was determined via Shapiro-Wilk test of normality. Within-session reliability was determined using 2-way, single-measure, random effects model intraclass correlation coefficient (ICC) and 95% confidence intervals (CI) and interpreted based on the lower bound CI as (<0.50) poor, (0.5–0.74) moderate, (0.75–0.90) good, and (>0.90) excellent (19). Percentage coefficient of variation (%CV) and 95% CI were also calculated to determine the within-session variability, with <10% classified as acceptable (10).

A series of paired samples *t* tests or Wilcoxon's test for variables that did not meet parametric assumptions, and Hedges *g* effect sizes were calculated to determine if there were any significant or meaningful differences between exercises. Because of multiple comparisons, subsequent Bonferroni's corrections were also applied. An a priori alpha level was set at $p \leq 0.05$, and effect sizes were interpreted as trivial (≤0.19), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), and very large (≥2.0) (17). Statistical analyses were performed using SPSS (Version 23. IBM, New York, NY), with individual plots, and Cumming's estimation plots were generated via www.estimationstats.com. Additionally, data are presented in Cumming estimation plots, with individual data, and paired mean difference is plotted as a bootstrap sampling distribution and 95% CI.

Results

Peak and mean EMG demonstrated good to excellent reliability (ICC ≥0.918; lower bound 95% CI > 0.8) between repetitions (Figure 2) with acceptable variability (<10%) in all conditions excluding peak GMax and mean BF both during the extension phase of the HE (10.86% and 10.35 %CV, respectively; Table 1).

For all muscle groups, peak EMG during the extension phase was significantly greater activation during the RHE, with moderate magnitudes ($p \leq 0.024$; $g \geq 0.95$; ES = 107.3 ± 37.9%, GMax = 49.3 ± 37.5%, and BF = 58.8 ± 21.7%) compared with HE (ES = 73.1 ± 25.4%, GMax = 18.1 ± 13.1%, and BF = 38.7 ± 18.6%). A similar pattern was also demonstrated during the flexion phase with RHE demonstrating significantly greater ($p \leq 0.024$; $g \geq 1.04$) peak EMG with moderate to large effect (ES = 101.6 ± 37.1%, GMax = 52.6 ± 33.6%, and BF = 58.9 ± 21.3%) compared with the HE (ES = 59.2 ± 29.1%, GMax = 15.4 ± 9.8%, and BF ≤ 37.3 ± 18.4%) (Figure 3).

Mean EMG followed a similar pattern for ES and GMax in both extension and flexion phases of the RHE (ES = 71.0 ± 20.5% and 51.8 ± 16.1%; GMax = 23.4 ± 15.8% and 18.6 ± 9.2%, respectively), exhibiting significant and moderate-to-large differences ($p < 0.001$; $g \geq 1.03$) compared with HE (ES = 43.9 ± 18.3% and 30.5 ± 11.3%; GMax = 8.2 ± 4.5% and 9.1 ± 6.5%) (Figure 4). During the extension phase, the BF again elicited a significantly and moderately greater ($p = 0.036$; $g = 0.75$) mean EMG during the RHE (39.7 ± 13.4%) compared with HE (28.5 ± 15.1%); however, the flexion phase resulted in nonsignificant and small differences ($p = 9.960$; $g = 0.30$) between RHE and HE (28.3 ± 2.3% and 22.4 ± 13.3%, respectively) (Figure 4F).

Discussion

The aims of this investigation were to assess the differences in surface EMG of the ES, GMax, and BF during both extension and flexion phases of the HE and RHE. In agreement with our hypothesis, both the peak and mean EMG were greater during the RHE when compared with the HE. Moderate-to-large significantly greater differences were observed in peak EMG of all 3 muscles during both the extension and flexion phases of the RHE with mean EMG demonstrating similar results to peak EMG for the ES and GMax. Mean BF EMG showed small and nonsignificant differences during the flexion phase of the exercises. These results indicate that the RHE is likely a more effective exercise for training the posterior chain compared with the HE because of the EMG amplitudes elicited in both extension and flexion phases of the exercise.

During both the extension and flexion phases, the RHE elicits moderate-to-large significantly greater EMG amplitude in the ES and GMax. The biomechanical similarity between the 2 exercises is not reflected in the magnitude of the activation relative to the maximum capability of the muscle isometrically (the MVIC). The ES evidently produces the greatest percentage of MVIC, when performing the RHE, during both phases. When considering the implications of this in practice, it may suggest that in certain settings, such as rehabilitation from injury, caution should be taken in selecting the RHE because of the very high muscle activation, and therefore, it may be more appropriate to use the HE as a regression, before progressing an athlete onto the RHE. A reason for the ES EMG values exceeding 100% of its MVIC could

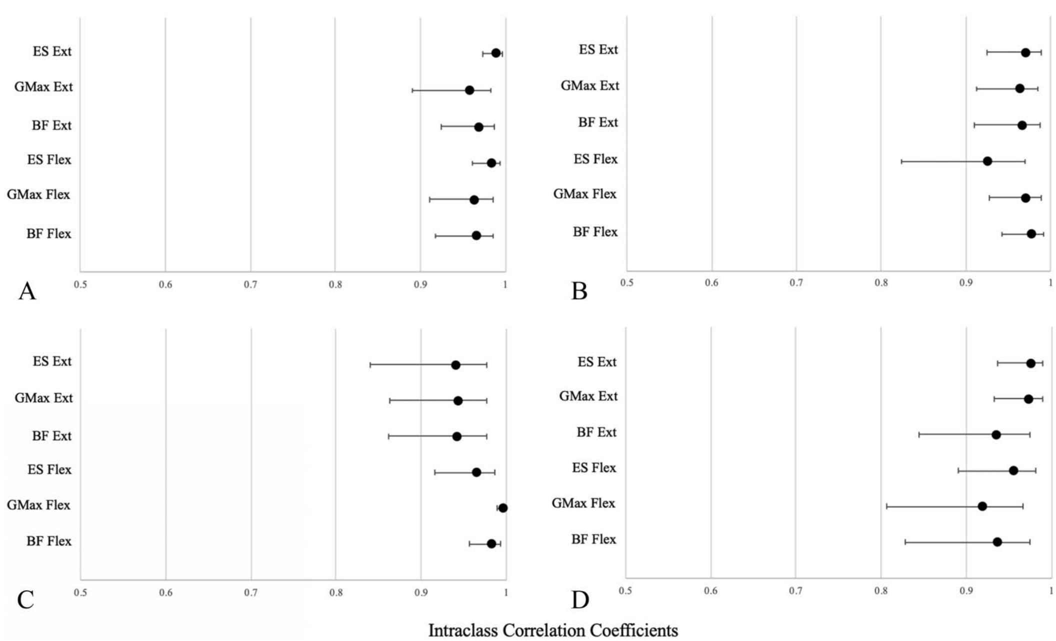

Figure 2. Reliability (intraclass correlation coefficients and 95% confidence intervals) for peak EMG (A) and mean (C) EMG amplitude during the hyperextension. B) Peak and mean (D) EMG amplitude during the reverse-hyperextension. ES = erector spinae; GMax = gluteus maximus; BF = biceps femoris; Ext = extension phase; Flex = flexion phase; EMG = electromyography.

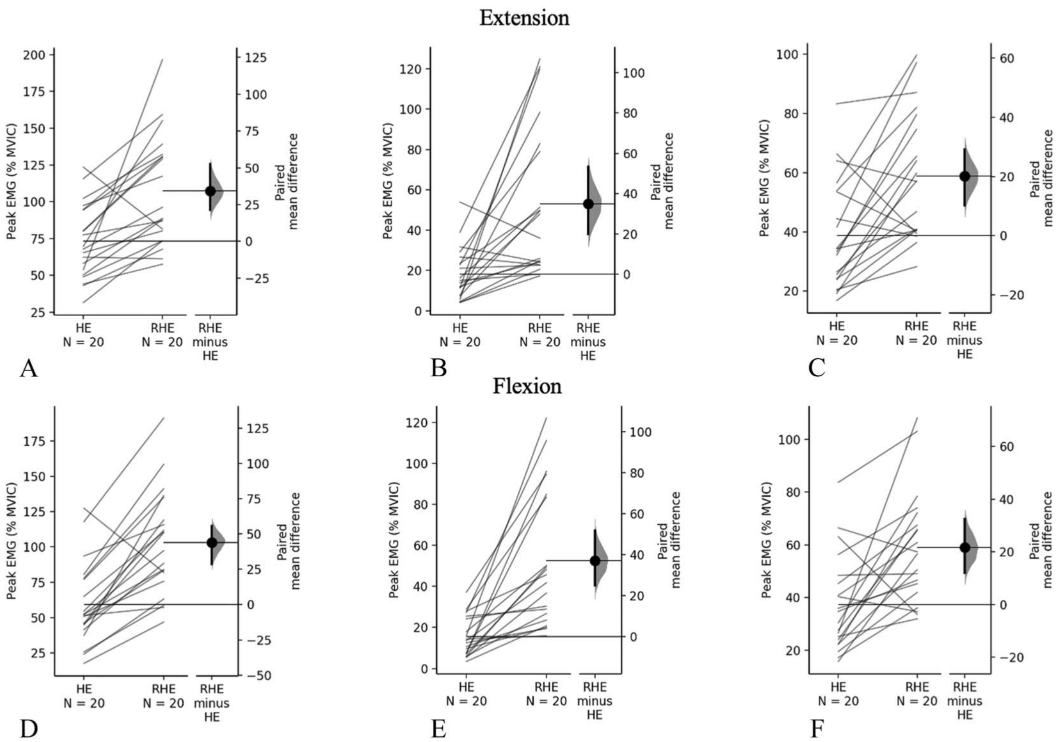

Figure 3. Comparison of normalized peak EMG of the (A) erector spinae (ES), (B) gluteus maximus (GMax) (C) biceps femoris (BF) between exercises during the extension phases and (D) ES, (E) GMax, (F) BF between exercises during the flexion phases. Individual data are plotted on the primary axis. Paired mean differences are plotted as a bootstrap sampling distribution on the secondary axis. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars. EMG = electromyography.

have potentially been do with the quality of normalization task chosen, with both GMax and BF normalization tasks being unilateral (hip extension and knee flexion) compared with of course a bilateral task (back extension) used for the ES, as well as a greater ROM during both the HE and RHE compared with the one static position held during the MVIC. Further to the differences in normalization tasks, there could have been preferential recruitment of the ES because of the technique adopted by the subjects. Macadam and Feser (23) highlighted how verbal and tactile cues increase GMax activation; therefore, without any specific cues given during the exercise, the subjects could have been preferentially using their ES and BF to a greater extent rather than achieving hip extension through gluteal activation. In comparison to a previous study examining the RHE, similar peak EMG values were seen in the ES because this was also above 100% of MVIC; in contrast, however, the HE also elicited ≥100% MVIC in the same study and with no significant difference present between the two (21). Another obvious difference between the study by Lawrence et al. (21) and the current study is that the EMG of the GMax during both exercises, which exceed 100% MVIC on average, compared with the current study whereby the GMax only elicits approximately 50% MVIC. The difference between the 2 studies again could be down to normalization protocols, considering that the study of Lawrence et al. (21) used a MVIC at the top of the extension phase of the HE, which could have been suboptimal for generating maximum contractions compared with separate tasks for each muscle group. The load used differed between the 2 studies also, with the current study using the equivalent of the subject's own upper-body weight, whereas the study of Lawrence et al. (21) used a similar calculation of upper-body weight with the addition of a 20.4 kg plate during the HE and the equivalent factoring in the pendulum arm and lower mass of the lower body. The difference in load could also account for some of the increase in activation because the GMax may have been required to a greater extent as a result of the ES and BF being overloaded.

The BF followed the same pattern as the ES and GMax in terms of peak EMG with the RHE demonstrating moderate, significantly greater activation during both phases. The only variable not to show a significant difference was in the mean EMG of the BF during the flexion phase, one reason for this could have been because of the subject's "relaxing" the load, be it upper-body weight or the equivalent lower limb plus the weight on the pendulum in a similar manner. In comparison to the previous literature, BF activation during the HE much like that of the ES and GMax is lower when compared with Lawrence et al. (21). As previously mentioned, Lawrence et al. (21) used an additional 20.4-kg plate for the HE, which could account for a portion of the increase in activation as findings from Zebis et al. (33) showed an approximately 20% increase in BF activation when load was added to the HE. In comparison to similar hip extension–based exercises (such as, 45° hip extension), activation produced during the RHE was similar to that of a 45° hip extension (6); however, caution must be taken when comparing EMG between studies because of variations in equipment, sampling frequencies, noise, amplification used, and filtering processes (28).

The individual differences in EMG between subjects are demonstrated by the range in standard deviations and can be seen in Figures 3 and 4. A limitation of this study based on the individual differences could be the heterogenous sample used. Although they were all collegiate athletes, there was mixture of male and female subjects of various body compositions. Because of this study using

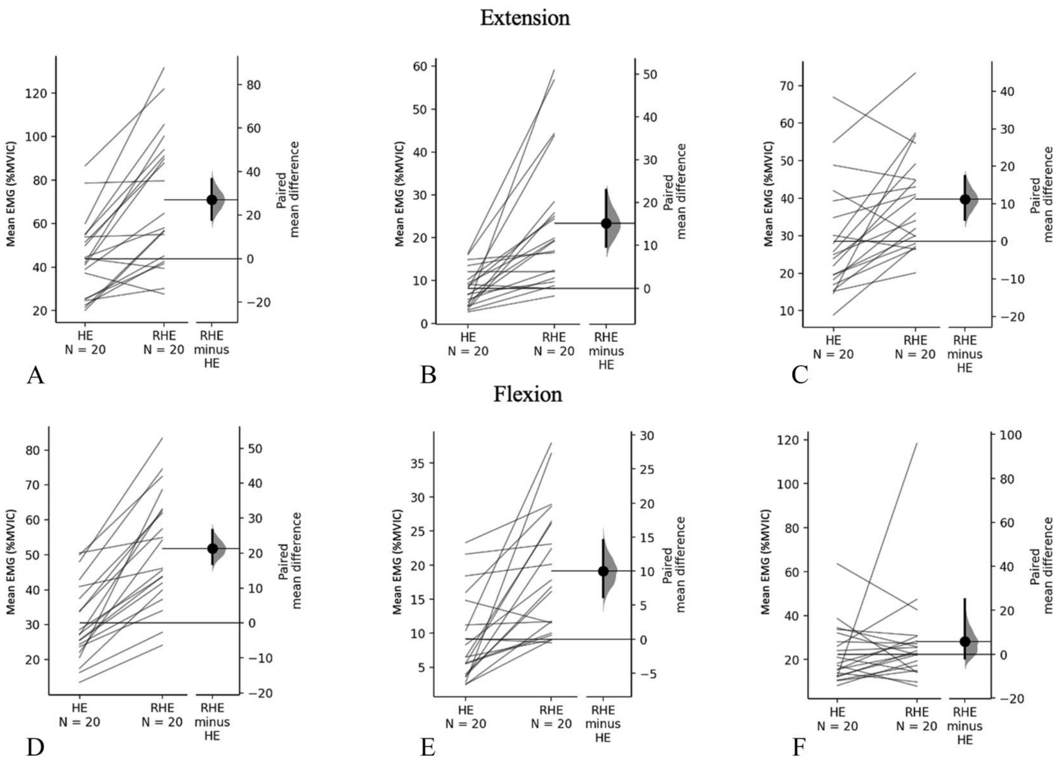

Figure 4. Comparison of normalized mean EMG of the (A) erector spinae (ES), (B) gluteus maximus (GMax), and (C) biceps femoris (BF) between exercises during the extension phases and (D) ES, (E) GMax, and (F) BF between exercises during the flexion phases. Individual data are plotted on the primary axis. Paired mean differences are plotted as a bootstrap sampling distribution on the secondary axis. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars. EMG = electromyography.

surface EMG, there are some pitfalls of the equipment that include lower EMG recordings because of increased subcutaneous fat, which can either reduce the detection or increase the cross-talk (24). Areas for future research include the effect of different cues on activation of the poster chain muscle groups during these exercises. Another potential area of future research is a comparison between unilateral RHE bilateral RHE particularly in ES activation because of the high levels of normalized EMG observed within this study. Following the identification of activation during these exercises, a training intervention should be applied to determine their adaptations to performance.

Practical Applications

Based on the differences between the HE and RHE demonstrated within this study, practitioners should consider the RHE as a higher-intensity exercise for the posterior chain muscles. Strengthening the hip extensors is important for improving different athletic tasks, such as sprinting and jumping, with the findings of this study suggesting that it is likely that the RHE would elicit greater increases in strength compared with the HE. It is also worth noting that because of the low level of activation observed (<20% MVIC), without necessary coaching intervention or the addition of load, the HE is unlikely to stimulate the GMax to a high enough extent. In addition, without appropriate cueing, the introduction of load could potentially increase the load on the spine rather than creating a greater stimulus for the GMax, which practitioners should be careful of.

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