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Are All Hip Extension Exercises Created Equal?

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ABSTRACT

TARGETED HIP EXTENSION EXERCISES ARE OFTEN PERFORMED TO DEVELOP STRENGTH, POWER, AND ENDURANCE IN THE HIP EXTENSORS. ALTHOUGH THESE EXERCISES CAN POSSESS SIMILAR MOVEMENT PATTERNS, BIOMECHANICALLY THE INSTANTANEOUS TORQUE AT DIFFERENT RANGES OF HIP EXTENSION VARIES DEPENDING ON BODY POSITION RELATIVE TO SPACE. FOR THESE REASONS, IT IS PROPOSED THAT: (A) HIP EXTENSION EXERCISES MIGHT TRANSFER BETTER TO SPORT ACTIONS WHERE THE REGION OF FORCE ACCENTUATION IS MOST SPECIFIC; (B) HIP EXTENSION EXERCISES MAY LEAD TO UNIQUE STRUCTURAL ADAPTATIONS; AND (C) A VARIETY OF EXERCISES MIGHT BE NECESSARY TO MAXIMIZE HIP EXTENSION STRENGTH AND POWER THROUGHOUT THE ENTIRE RANGE OF MOTION.

INTRODUCTION

The muscles of the posterior chain, especially the hip extensors, are highly important in maximum speed and power production during activities, such as sprinting and jumping (1,2,21,22). For this reason, squat, Olympic-style lift, deadlift, and lunge variations are considered staple exercises in a strength and conditioning practitioner's program, and targeted hip extension exercises often fall into a strength coach's top 5 most important exercises (8–11,27). Three targeted hip extension exercises commonly performed in athletic weight rooms are the good morning, the 45° back extension, and the horizontal back extension. Each of these exercises can be classified as "hip dominant lifts" as they act primarily on the hip joint, as long as the performance of the 3 exercises involves flexing and extending the hips while keeping the spine and pelvis in relatively neutral positions. Because the knees do not bend substantially during each of these movements, they could be classified as "straight-leg hip extension exercises."

Given the similarity in movement patterns, it would seem that the aforementioned hip extension exercises are interchangeable. In other words, strength and conditioning practitioners would typically assume that there is little difference in the performance and imposed training adaptations between the 3 exercises. However, a biomechanical analysis of these variations has not yet been conducted in the literature making any inferences as to their interchangeability speculative at best.

It is of utmost importance for strength coaches to design programs that transfer to sports performance, and one such way of attempting to maximize transfer of training is to use the principle of dynamic correspondence. Siff (26) described dynamic correspondence as "how closely the means of special [sport-specific] strength preparation corresponds to the functioning of the neuromuscular system in a given sport." One of the principles of dynamic correspondence is the accentuated region of force production. If it was shown that the direction of the human body relative to space led to varying accentuated regions of force production in the good morning, the 45° back extension, and the horizontal back extension exercises, a case could be made that the different hip extension exercises are better suited to transfer more toward particular sport actions and lead to unique structural adaptations. Moreover, combining these exercises in a training program might have a synergistic effect for sports that require high levels of force production at different hip angles.

BIOMECHANICAL ANALYSIS OF SELECTED HIP EXTENSION EXERCISES

Basic physics can be used to facilitate a better understanding of the hip biomechanics in each of the 3 straight-leg hip extension exercises, whereby instantaneous external torque is calculated at 90° hips-flexed positions (think

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of a standing person bent over so that the torso is parallel to the ground and the torso forms a right angle with the legs), 135° hips-flexed positions (think of a half-way position between being bent over and standing straight up), and 180° hips-neutral positions (think of a person standing straight up so that his torso and legs form a straight line); for visual representations, see Figure 1. To illustrate these calculations, we used a hypothetical athletic reference individual (an athletic individual will likely store a greater proportion of his torso mass in the upper torso compared with a sedentary individual) and made a number of assumptions, including:

1. The spine and pelvis stay locked in neutral positions while the entire movement occurs at the hips.
2. The hips flex to 90°, which would require good levels of hamstring flexibility.
3. The knees stay relatively straight in each variation.
4. The good morning exercise does not involve any "sitting back" or knee flexion, which is not truly representative of how the movement actually occurs. This allows for simpler calculation while not drastically altering the external hip torque measurement.
5. The head, arms, and trunk (HAT) comprise 68% of the individual's body weight (29).
6. The average center of mass of the HAT is located 0.40 m from the hips.
7. Arm position is in a similar position in all the 3 exercises so that the HAT center of mass is unaffected.
8. The individual is 6 feet (182 cm) tall and weighs 194 lb (88 kg).
9. Each movement is performed slowly to eliminate the effects of momentum, which might not be truly representative of how the movements really occur.
10. The average center of mass of the additional load is located 0.55 m from the hips.
11. The additional load used in each exercise is 100 lb (45 kg).

Simplifying biomechanical calculations in this way enhances our understanding of the mechanical advantages of the 3 different hip extension exercises discussed in this article, helping to guide the practitioner as to their application in program design. It should be noted, however, that the aforementioned assumptions could somewhat skew the precise mechanical advantage during actual performance. In regard to the effects of momentum on hip extension torque, Lander et al. (17) found that joint moments varied less than 1% between quasi-static (loading where the inertial effects are negligible) and dynamic analyses during the squat exercise with near maximum loads because of the inherent slow velocities and accelerations. Although 100 lb would not necessarily represent maximal loading and thus would not allow for the use of quasi-static models, it provides a simple means to predict torque-angle curves at the hips during hip extension exercises at different body positions. Figure 1 depicts the exercise positions analyzed.

CALCULATIONS

Each exercise position required the calculation of 2 moments: the moment of the HAT acting on the hip joint and the moment of the 100 lb (45 kg) external resistance acting on the hip joint. Figure 2 illustrates a sample calculation. The calculations are derived as follows:

1. Calculate the weight of the HAT by multiplying the individual's body weight by 0.68 (68%).
2. Convert the weight of the HAT to Newtons by multiplying the weight in kilograms by 9.8 (which is the gravity of Earth, measured in meters per second squared).
3. Calculate the external torque of the HAT acting on the hip by multiplying the weight of the HAT (in Newtons) by the perpendicular distance from the hip to the HAT center of mass.
4. Convert the weight of the free weight implement to Newtons by multiplying the weight in kilograms by 9.8 (which is the gravity of Earth, measured in meters per second squared).
5. Calculate the external torque of the free weight load acting on the hip by multiplying the weight of the implement (in Newtons) by the

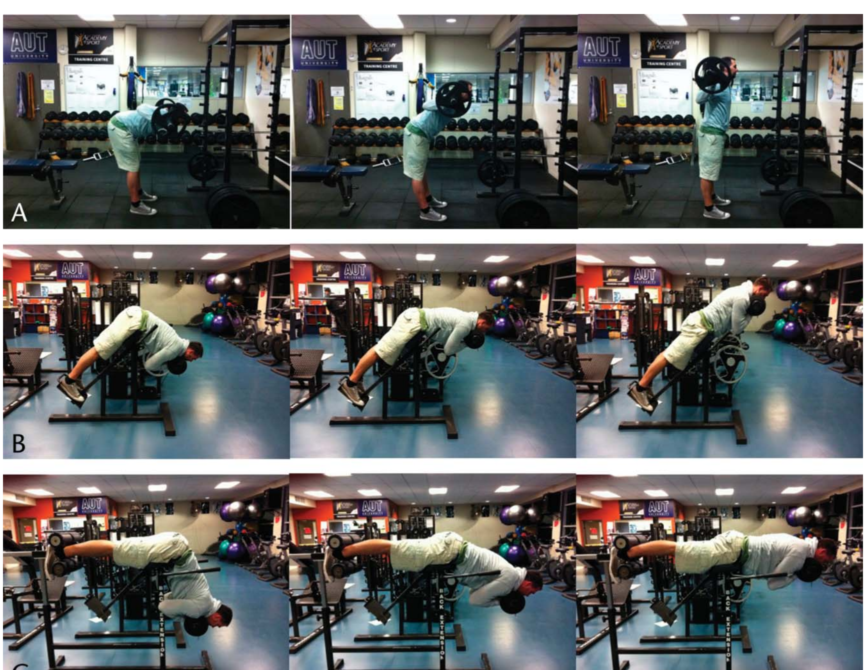

Figure 1. (A) Good morning exercise: 90°, 135°, and 180° of hip extension. (B) 45° Back extension exercise: 90°, 135°, and 180° of hip extension. (C) Horizontal back extension exercise: 90°, 135°, and 180° of hip extension.

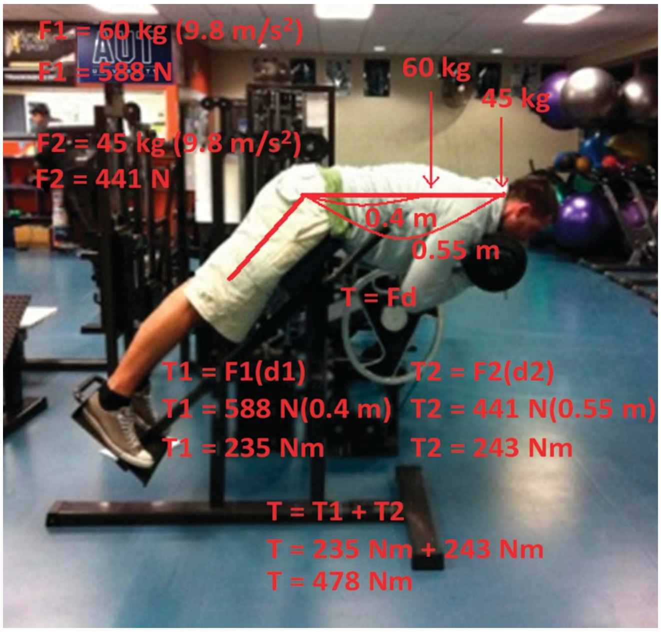

Figure 2. Sample calculation for 45° back extension exercise at a hip position of 135°.

perpendicular distance from the hip to the implement center of mass.

6. Add the 2 external torques together. The 9 different calculations are summarized in the Table, with the precise calculations of hip torque provided for the various straight-leg hip extension exercises. Note the relationship between the various positions in the hip extension exercises. Given maximum instantaneous hip torque (labeled X), the top row shows X, 0.71X, and 0; the middle row shows 0.71X, X, and 0.71X; and the bottom row shows 0, 0.71X, and X.

PRACTICAL APPLICATIONS

It is evident from the previously described calculations, hip torque varies considerably throughout hip extension range of motion depending on the position of the upper body relative to the axis of rotation, that is, hip joint. During the good morning exercise, hip torque is highest (i.e., 478 Nm) in a 90° hips-flexed position and diminishes throughout the concentric portion of the repetition, reaching its lowest value (i.e., 0 Nm) in a hips-extended position (i.e., 180° or fully extended). In the case of the 45° back extension, hip torque is highest (i.e., 478 Nm) in a 135° mid-range hip position and the hip torque is more consistent throughout the range of motion, never dropping below 338 Nm. The horizontal back extension creates very little hip torque in a hips-flexed position (i.e., 0 at 90° of hip flexion) but increases steadily throughout the concentric portion of the repetition, reaching its apex (i.e., 478 Nm) when the hips are fully extended (Figure 3).

To overcome inertia of the system (barbell plus body mass), hip extensor muscle force (passive and active) must exceed the torques shown in the different positions that can be observed in Figure 2 because internal forces must be greater than external forces in order for concentric movement to occur. Granted athletes often perform these movements explosively, but with higher percentages of 1 repetition maximum, the effects of momentum are minimized, enabling a suitable model for analysis.

Because a definition in the literature is lacking, one could refer to single-joint exercises that create maximum torque while the prime movers are stretched as "long-length accentuated force exercises." Conversely, one could refer to single-joint exercises that create maximum torque while the prime movers are shortened as "short-length accentuated force exercises." Exercises that create maximum torque while the prime movers are between either extreme would be considered "mid-length accentuated force exercises." Using our hip extension exercises as examples, the good morning exercise would be considered a long-length accentuated force exercise, the horizontal back extension exercise would be considered a short-length accentuated force exercise, and the 45° back extension exercise would be considered as a mid-length accentuated force exercise.

This language works well with monoarticular muscles but is tricky with biarticular muscles. For example, consider the hip extension exercises discussed herein. During straight-leg hip extension, the gluteus maximus, a monoarticular muscle, is in a long-length position with hips flexed and a short-length position with hips extended. However, although the hamstrings, a biarticular muscle, shorten as the hips extend, they could be markedly shorter if the knees are flexed. By examining Figure 3, it appears that long-length accentuated force exercises have ascending strength

Table
Instantaneous hip extension torque at selected ranges in 3 different straight-leg hip extension exercises

Exercise	Instantaneous hip extension torque, Nm		
	90°	135°	180°
Good morning	478	338	0
45° Back extension	338	478	338
Horizontal back extension	0	338	478

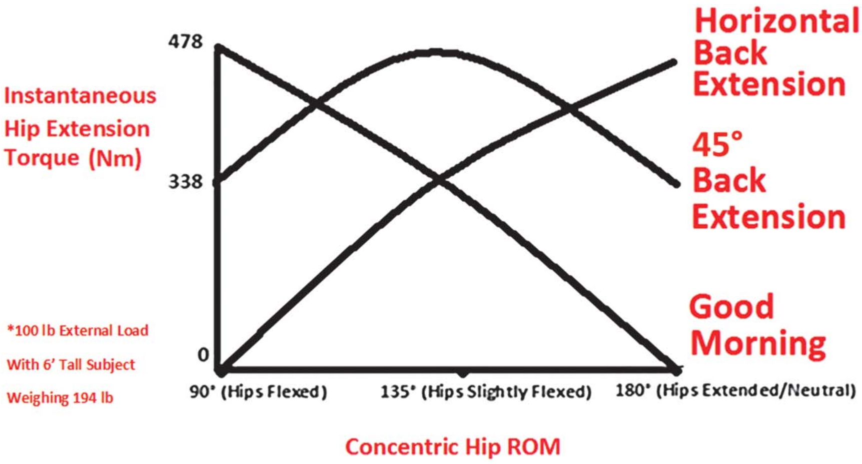

Figure 3. Graph of instantaneous hip extension torque at selected ranges of motion in 3 different hip extension exercises.

curves and descending torque-angle curves, mid-length accentuated force exercises have U-shaped strength curves and upside-down U-shaped torque-angle curves, and short-length accentuated force exercises have descending strength curves and ascending torque-angle curves. Moreover, this language is better suited for single-joint movements compared with multi-joint movements, as when adjacent joints move simultaneously it can enhance or diminish the lengthening of a muscle. For example, the biarticular hamstrings do not undergo much length change during performance of the squat given their dual role as knee flexors and hip extensors (23); when one joint is lengthening, the other is shortening.

If attempting to maximize carryover to sport action, it may be wise to select the exercise that most appropriately mimics the hip torque curve involved in the action. For example, because the good morning exercise maximizes hip torque in a flexed position, it may transfer better to the glute functioning involved during the late swing phase of sprinting, given that it maximizes hip torque in a flexed position, whereas the horizontal back extension may transfer better to the glute function involved during the stance phase of sprinting, given that it maximizes hip torque in an extended position. The 45° back extension may be best suited to the acceleration phase of sprinting because of the maximization of hip torque in the middle range of the hip flexion-extension axis, which is more closely associated to the region of ground contact involved in the first few seconds of a sprint.

At ground contact in maximal speed sprinting, the glutes are at short lengths, whereas the hamstrings are at long lengths. Gittoes and Wilson (14) showed that the hip and knee angles from touchdown to toe-off during maximal speed sprinting were approximately 150–175° and 155–145°, respectively. It would therefore make sense to strengthen these muscles at their corresponding lengths when attempting to maximize carryover, especially considering that exercise has been noted to influence the optimal length of a muscle (3). This could be coined "torque-angle specificity" or "force-range of motion specificity." However, contradictory research has recently emerged in this particular area. Clark et al. (7) showed that bench press training at a variety of ranges of motion and muscle lengths yielded greater benefits when compared with full range of motion bench in terms of mid-range reactive strength and end-range force production during isokinetic testing while not impairing initial-range performance. Yet Hartmann et al. (15) showed that although partial squats yielded superior results in terms of end-range strength production compared with full-range squats, partial squat training led to inferior results in terms of jumping performance, maximum voluntary contraction, and rate of force development and diminished initial-range squat performance. Further research is needed to elucidate these apparent contradictions.

Regarding hypertrophic adaptations, it has been proposed that the 3 primary mechanisms leading to muscular growth are mechanical tension, muscular damage, and metabolic stress (24). With respect to mechanical tension, exercises create varying amounts of external torque throughout a joint's range of motion (Figure 3). Anecdotally, exercises that produce high torques at long muscle lengths tend to create the most delayed-onset muscle soreness, most likely as a result of the damage of the stretched sarcomeres (e.g., flies and the pectorals, lunges and the glutes, and good mornings and the hamstrings), which theoretically could enhance hypertrophy because of the muscular damage incurred (25). In addition, anecdotally, exercises that produce high torques at mid-range and shorter muscle lengths tend to create the most metabolic stress. For example, some exercises are well known for creating a "pump" effect (e.g., cable crossovers and the pecs, hip thrusts and the glutes, and seated band leg curls and the hamstrings), better known to researchers as cell swelling, which has been proposed to enhance hypertrophy (24). Furthermore, exercises that keep consistent torque on the targeted joint, such as the 45° hyper, would theoretically occlude the most blood flow and lead to the most hypoxia, which has been proposed to enhance muscular hypertrophy through mechanisms involving metabolic stress (28). These hypotheses warrant further investigation.

Muscle damage associated with eccentric training can lead to sarcomerogenesis through 2 different proposed mechanisms (5), and it stands to reason that eccentrics with accentuated force production at long lengths would lead to increases in sarcomeres in series, thereby increasing muscle length. These adaptations can improve athletic performance by increasing contractile velocity and power (4). Furthermore, because the protein titin is proposed to contribute considerably to passive muscle force when a muscle is actively stretched to long lengths (18,20), one could speculate that long-length accentuated force exercises do a better job of creating passive tissue adaptations than short-length accentuated force exercises, which could be beneficial for elastic strength. Strength and power athletes have been shown to possess unique titin adaptations compared with controls (19), and targeted long-length training could potentially enhance such effects.

By examining Figure 3, because short-length accentuated force exercises require a "ramping up" of muscle force throughout the concentric range of motion, they might be better suited for accelerative purposes than long-length accentuated force exercises, given that muscle force diminishes during long-length accentuated force exercises throughout the concentric range of motion. However, considering that isometric training at longer muscle lengths has been shown to increase tendon stiffness and maximum voluntary contraction throughout the entire range of motion, the same cannot be said of isometric training at shorter lengths, an argument could be made that long-length accentuated force exercises are superior to short-length accentuated force exercises in terms of tendon and maximum voluntary contraction adaptations (16). However, this would require taking a big leap in logic because training effects from isometric exercises do not necessarily match those of dynamic exercises. Cavagna (6) showed that the work performed by the contractile components decreases with increasing speed because of a greater proportion of the length change taken up by the tendons as well as decreasing force owing to the force-velocity relationship, implying that range-specific isometric muscle force coupled with elastically-efficient tendons is a characteristic of high-velocity sprinting and that concentric power is more important during acceleration sprinting.

Based on the calculated external torques, it is apparent that relatively light external loads (i.e., 100 lb) can be used during straight-leg hip extension exercises to create considerable peak hip extension torque (i.e., 478 Nm) owing to long resistance moment arms. For comparative purposes, Escamilla et al. (12) showed that powerlifters with an average body weight of 201 lb and an average maximal squat of 497 lb imposed 628 Nm of peak hip extension torque during the squat exercise, and Escamilla et al. (13) reported that powerlifters with an average body weight of 169 lb and an average maximal deadlift of 489 lb imposed 599 Nm of peak hip extension torque during the deadlift exercise. Clearly, the squat and deadlift allow for heavier loads, but as a result of their shorter resistance moment arms, they do not dramatically exceed the hip extension torques required of straight-leg hip extension movements because the longer resistance moment arms counteract the effects of the lighter loads; however, we only analyzed the hip joint and not the external torques at the ankle, knee, or spine. Thus, training angle is an important consideration with respect to exercise selection in program design.

CONCLUSIONS

All hip extension exercises are not created equal. External torque varies depending on the position of the human body relative to the ground. Standing hip extension exercises exhibit their highest instantaneous torque when bent forward to 90°. Hip extension exercises performed at a 45° angle have more consistent levels of instantaneous torque throughout the movement. Horizontal hip extension exercises exhibit their highest level of instantaneous torque when the hips are extended. One can logically conclude from this brief treatise that multiple hip extension exercises should be performed for maximum balance of hip strength throughout the entire hip extension range of motion. Furthermore, it may be that athletes should be assessed over the entire range of motion to determine strength deficits, which in turn should result in better strength diagnosis and individualized programs. Finally, the strength and conditioning practitioner needs a higher order understanding of exercise and accentuated force/torque production in relation to the activity or event of interest. That is, for optimal transference from the strength and conditioning facility to the competitive environment (dynamic correspondence), careful consideration needs to be given to exercise choice.

Future research should be conducted involving 3D motion capture, force plate, and electromyography to calculate real-life hip extension moments. Furthermore, future research should be conducted to determine if the various hip extension exercises do in fact lead to unique structural adaptations and carryover to functional activities, such as running and jumping.

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