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Modulating the Nordic Hamstring Exercise From "Zero to Hero": A Stepwise Progression Explored in a High-Performance Athlete

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Background: The Nordic hamstring exercise (NHE) is commonly implemented to selectively improve eccentric knee-flexor strength. However, the standard version of the exercise (leveled shanks, extended hip joint) is too strenuous for most individuals, whose muscle activity rapidly decreases at extended knee angles. Hitherto, a gradual approach to the exercise has been missing. In this exploratory case study, we investigated elite performance to introduce a stepwise progression to the NHE.

Objective: To determine the extent to which exercise modifications (shank inclination, additional load, hip flexion) altered NHE mechanics.

Data Collection and Analysis: One male long jumper (age = 33 years, height = 171 cm, mass = 69 kg) with high-level expertise in the NHE performed 20 exercise variations. The corresponding kinematics, kinetics, and electromyographic activity of the biceps femoris long head (BFlh) and semitendinosus (ST) muscles were evaluated.

Results: Exercise variations demonstrated gradually increased peak moments from 69% (zigzag pose) to 154% (inclined bent single-legged version) versus a standard NHE. Shank inclination and additional load elicited small to moderate effects on peak moments, BFlh, and ST ($0.24 \leq d \leq 0.72$), whereas hip flexion largely affected all tested variables ($2.80 \leq d \leq 6.66$), especially muscle activity (BFlh = −63%; ST = −55% of maximal voluntary isometric contraction).

Commentary: These insights will help practitioners and scientists design multifaceted stepwise NHE progressions by creating differentiated stimuli that best match the strength capacities of individuals and address their specific needs.

Key Words: eccentric resistance training, exercise quality, hamstring strength, kinematic analysis, peak moments, muscle activity

Key Points

- A regression and progression of the standard version of the Nordic hamstring exercise (NHE) is justified to adapt the stimuli to the specific needs and capacities of each individual in order to guarantee high-level hamstring activation and strength capacities in extended knee angles.
- A 6-level stepwise progression model is introduced, which consists of 15 exercises that demonstrated gradually increased peak moments from 69% to 154% versus a standard NHE.
- Five standardized cutoff exercises enable an uncomplicated classification of each individual by performance level.
- Three exercises favored greater biceps femoris long head activation, which is vital for effective injury prevention, rehabilitation, and performance enhancement.
- Hip flexion largely affected peak moments and biceps femoris long head and semitendinosus activity, whereas shank inclination and additional load elicited small to moderate effects.

First introduced in 1880,[1] the Nordic hamstring exercise (NHE) has become a popular resistance-training exercise to improve eccentric knee-flexor strength[2–5] as well as the performance of sprints[5,6] and jumps.[7,8] Athletes who regularly implement the NHE have an average 51% reduction in the incidence of hamstring strain injury,[9,10] which emphasizes its high efficiency for mitigating the injury risk.[9–13] Furthermore, the NHE is recommended for preventing anterior cruciate ligament injury.[14] Its supramaximal eccentric nature and highest knee-flexor activation has not been replicated by any other exercise.[12,15–17] The debate about whether the NHE elicits higher peak activation of the semitendinosus (ST) muscle or the predominantly injured biceps femoris long head (BFlh) muscle is still ongoing.[17,18] Practitioners and scientists question the practicality of the NHE because of its difficulty, bilateral nature, and predominant knee movement (with a negligible hip range of motion[2] of approximately 20°), which does not appear to promote activation of the BFlh.[8,19,20]

Given the lack of eccentric hamstring strength, most athletes demonstrate downward acceleration (DWA) within the first half of the exercise's range of motion ($ROM_{DWA} <$ 50%).[21] The end of the controlled movement during NHE execution coincides with peak muscle activation at a rather short muscle length (70° to 50° of knee flexion), followed by a rapid decrease at the end of the exercise.[22] The length-at-use and contraction-mode hypotheses emphasized that muscles adapt according to their common tasks and imposed demands.[23,24] Therefore, consistently high muscle activation and a certain time under tension at injury-related extended knee angles (approximately 30° to 0° of knee flexion)[20–22,25] were essential for angle-specific adaptations after eccentric training.[26] These adaptations are needed for effective injury prevention and rehabilitation as well as for performance enhancement[5,19,27] because the muscle-tendon units must withstand higher moments[2,15,28,29] at longer muscle length, which promotes muscle-tendon adaptations such as the addition of sarcomeres in series.[30] Furthermore, the biceps femoris is selectively activated at extended knee angles[27] and when hip extension is superimposed on eccentric knee flexion.[31] To delay the onset of DWA in the first third of ROM and promote consistently high muscle activation during the progressively increasing gravity-induced overload,[15,29] facilitations such as assistance (eg, elastic bands),[27,28,32–34] shank inclination,[35] and hip-flexion angle[27,35] are suitable tools for customizing and progressing the NHE. Therefore, their implementation is recommended for beginners and young, injured, or weaker individuals[6,7,36,37] to gradually learn and adapt the NHE technique according to their specific needs and physical capacities.

To the best of our knowledge, a progression model for the very demanding NHE has not been introduced. Such a model would allow stepwise gradation and monitoring of eccentric loading of the knee flexors during every training session. To explore the characteristics of NHE variations in a standardized and highly reproducible manner at constant movement speed throughout the entire ROM, it is reasonable to first analyze the exercise as performed by a participant who possesses full control throughout the entire activity. An NHE progression might help reduce the consistently high incidence of hamstring injury[9,10,19] by enlarging the "muscle's safe operating range,"[32] promoting muscle-tendon interaction,[38,39] and avoiding excessive fatigue due to individual overloading.[26,28]

Consequently, the purpose of our exploratory case study was to investigate the kinetics, kinematics, and electromyographic (EMG) activity of NHE variations (facilitations and intensifications) as performed by 1 participant with a high level of expertise to establish a scientifically evaluated stepwise progression to the NHE. Furthermore, we wanted to determine which exercise modifications (shank inclination, additional load, hip flexion) had greater influence on NHE kinetics and muscle activation. Another purpose was to establish standardized cutoff exercises that separate different exercise levels to easily assign individuals to an NHE performance level. Also, we hoped to identify which NHE variations promoted the activation of the BFlh and the ST muscles. The study was founded on the following hypotheses: (1) The NHE peak moment and peak muscle activity would be substantially progressed by exercise variations that incorporate shank inclination, additional load, and hip flexion. (2) When performed at a high level, the NHE and its variations would demonstrate balanced peak muscle activity of the BFlh and the ST.

CASE PRESENTATION

Participant

The participant was a regional-class male long jumper (age = 33 years, height = 171 cm, mass = 69 kg) with a high level of expertise in the NHE. He had 6 years of experience with NHE training (≥1 session per week) and no thigh muscle or knee injuries in the last 5 years. A standard NHE was moderately difficult for him when he was not fatigued (visual analog scale rating = 5; Figure 1). Our ambitious aim was to evaluate all NHE variations at constant movement speed throughout the entire ROM. Hence, the sample size could not be increased because few individuals were able to perform such challenging exercise variations. The participant was familiarized with all exercise variations and the testing procedures in 5 sessions (separated by 3–5 days each). Seven days later, he completed 3 test sessions (72 hours apart). The participant provided written informed consent, and the Ethics Commission of TU Dortmund University approved the study.

Intervention

Testing Procedure. After an individual warm-up (10 minutes of jogging, isometric hamstring preactivation), skin preparation (shaving, skin exfoliation, hydration, alcohol swab), and EMG sensor attachment, the participant underwent a signal inspection (ie, signal-to-noise ratio) to ensure accurate signal detection. Twenty facilitating and intensifying NHE variations were analyzed during 3 test sessions (Table; Figure 2). Before the NHE analyses, he performed two 4-second maximal voluntary isometric contractions (MVICs) in the NH plank activation pose (Figure 2C) with oral encouragement. During each of the 3 test sessions, the order of the exercises was stratified according to their expected peak moments.

The participant knelt on the edge of cushioned pads (Figures 1 and 2) to ensure that the articular cartilage of the tibial head rolled smoothly underneath the patella.[37] For inclined exercises, a custom-built wooden ramp (elevated approximately 30°) was used (Figure 2D–2F). For isometric exercises, the participant (1) gradually increased the generated moment over 2 seconds and (2) held the maximal exertion for 4 seconds. For dynamic exercises, the execution quality criteria were to (1) execute the eccentric part with a time under tension of approximately 6 seconds until full knee extension and (2) attain the desired hip flexion (0° or 90°) with (3) his hands crossed in front of the chest. For exercises with an extended hip joint, emphasis was put on isometric gluteus activation at the end of the movement (Figure 1). Two examiners (T.R., K.N.) checked the execution criteria throughout the entire study. If the criteria were not met, trials were repeated until 3 valid repetitions were accomplished. All exercises were performed as single repetitions (2-minute inter-repetition rest, 10 minutes between exercise variations) to prevent excessive fatigue. Given their high level of strain, single-legged exercises were executed and evaluated only once. To allow

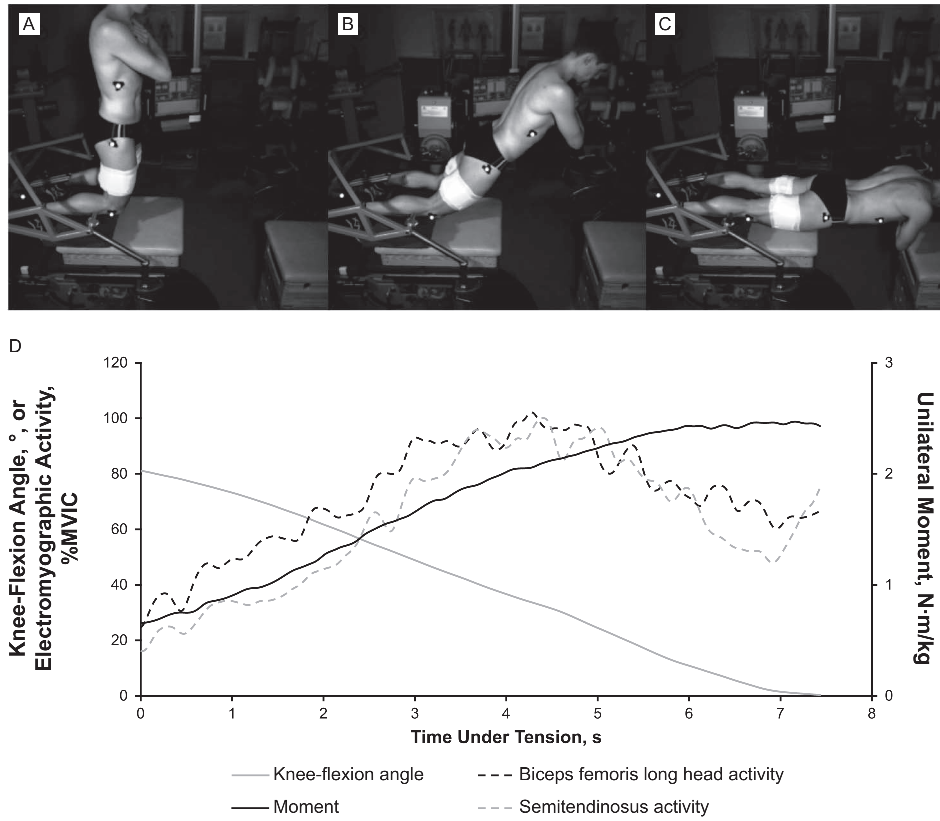

Figure 1. Representative illustrations of A, starting; B, mid-range of motion; and C, end positions; and D, corresponding kinetic (unilateral moment), kinematic, and electromyographic data of the Nordic hamstring exercise standard version (level 4A) using a custom-built frame mounted to the axis of the dynamometer. Throughout the entire knee range of motion (81.6° ± 1.1°), the knee-extension velocity was consistently low (mean = 11.1°/s ± 0.6°/s), and hip flexion was as small as possible (maximum = 8.7° ± 1.0°; see Supplemental Table). In the end position, special emphasis was placed on isometric gluteus activation. Abbreviation: MVIC, maximal voluntary isometric contraction.

us to obtain isokinetic movement velocity, the participant received live visual feedback on a 21.5-inch (54.61-cm) monitor (model KA221Qbid; Acer) showing a stick figure moving at target speed overlaid with a webcam video (30 frames per second; model C200; Logitech) captured from a position perpendicular to the sagittal plane.[2,5,28] Assisted variations were conducted via rope-controlled resistance transferred to a climbing harness (model Newton; Petzl; Figure 2F). The examiner adapted the resistance according to the live feedback.[2,5,28] A 5-kg plate held in front of the chest served as additional load (Figure 2I). The bouncing NH plank was performed at a 1-Hz cadence standardized using a metronome. For decelerated trials, the participant was instructed to fall as fast as possible before maximally decelerating his trunk (Figure 2I).

Fundamental Principles of the Stepwise Progression Model. The difficulty of the NHE variations was ranked according to the peak moment. Exercises were then clustered into distinctive levels with respect to gradually increasing peak moments and common characteristics (eg, shank inclination, hip-angle configuration). Another purpose of the stepwise progression model was to identify standardized cutoff exercises that separate the different exercise levels to allow uncomplicated classification of each person into an NHE performance level.

Instruments. The participant's anthropometric data were collected according to the Hanavan model.[40] All exercises were performed in a laboratory using an isokinetic dynamometer operating at 0°/s (model IsoMed 2000; D&R Ferstl GmbH). A custom-built frame mounted to the dynamometer axis (Figure 1) was used to assess unilateral moments (200 Hz; version 2.0; IsoMed Analyze) that were synchronized (model NI USB-6210; National Instruments Corp) with the motion capture (model TEMPLO 2019.1.578; Contemplas GmbH), which was conducted using 2 high-speed video cameras (100 frames per second; model DR1-D2048-192-G2; Photonfocus). Headlights (model F02T75; Aeon Lighting Technology Inc) improved the visibility of the retroreflective markers (diameter = 16 mm) attached to the participant's body (sixth rib, trochanter major, lateral femoral epicondyle) and the dynamometer's lever arm (Figure 1). The testing environment was calibrated using a calibration frame (157 × 60 × 124 cm) and star (40 × 40 × 40 cm) mounted to the axis of the dynamometer. All kinematic analyses were performed using Motus (version 10.0.1; Vicon Motion Systems, Inc). The muscle activity of both posterior thighs (BFlh, ST) was recorded using a Trigno Wireless System (Delsys Inc) at 2000 Hz. Consistent with the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) guidelines,[41] 4 Trigno Avanti sensors (27 × 37 × 13 mm) were attached to the muscle bellies and fixed using adhesive tape.

Data Processing

The EMG signals were sampled at 2000 Hz (model NI USB-6210; National Instruments) and synchronized to the

Table. Classifying Overview of the 20 Facilitating and Intensifying Nordic Hamstring Exercise Variations Within the 3 Test Sessions

Exercise[a] (No. = 20)	Knee Angle, °	Hip Angle, °	Shank Inclination, °	Comment	Test Session 1	2	3
Isometric poses (No. = 5)							
Zigzag pose	45	90	0	Static	X		
Nordic hamstring plank pose	0	0	0	Static	X		
Extended Nordic hamstring plank pose	0	0	0	Static and extended upper limbs over the head		X	
Loaded Nordic hamstring plank pose	0	0	0	Static and 5 kg of additional load		X	
Single-legged zigzag pose	45	90	30	Static and unilateral			X
Adapted activation (No. = 3)							
Zigzag activation	45	90	0	Individual effort	X		
Nordic hamstring plank activation[b]	0	0	0	Individual effort	X	X	X
Guided final stage activation	30–0	0	0	Individual effort	X		
Inclined Nordic hamstring exercise (No. = 7)							
Bent version	60–0	90	30			X	
Loaded bent version	60–0	90	30	5 kg of additional load		X	
Inclined Nordic glute raise	0	90–0	30	Dynamic			X
Standard version	60–0	0	30				X
Loaded standard version	60–0	0	30	5 kg of additional load			X
Assisted bent single-legged version	60–0	90	30	Unilateral and assistance			X
Bent single-legged version	60–0	90	30	Unilateral			X
Leveled Nordic hamstring exercise (No. = 5)							
Bent standard version	90–0	90	0		X		
Standard version	90–0	0	0		X		
Bouncing Nordic hamstring plank	0–10	0	0	Dynamic and 1-Hz cadence		X	
Decelerated standard version	90–0	0	0	Deceleration		X	
Loaded decelerated standard version	90–0	0	0	Deceleration and 5 kg of additional load		X	

Abbreviation: MVIC, maximal voluntary isometric contraction.

[a] Single-legged exercises were executed and evaluated once.

[b] Used for MVIC measurements to quantify the 100% electromyographic activity.

dynamometer (200 Hz) and video data (100 Hz). The EMG signals were bandpass filtered using a recursive fourth-order Butterworth filter at 10 to 500 Hz,[27,31] and then a moving root mean square filter with a 250-millisecond window width was applied.[34] Afterward, normalized signals were smoothed using a fourth-order, zero-lag low-pass Butterworth filter at 5 Hz.[34] The peak muscle activity of each muscle during the MVIC measurements was averaged over 1 second.[27,31] Custom-made software written in C++ was used to filter the force data via a fifth-order, zero-lag low-pass Butterworth filter at 6 Hz and extract all relevant kinetic and kinematic measures of NHE performance[2,5,28]: peak moment, angle of peak moment, time under tension, knee-flexion and hip-flexion angles, joint-angle velocities (ω), and peak muscle activation (peak BFlh, peak ST). Misalignment between the dynamometer and the knee-joint axis was corrected using the camera data and inertial segment properties based on the Hanavan model.[40] The resultant NHE peak moments were averaged for a single limb (bilateral asymmetry <5%) and normalized to body mass.

Comparative Outcomes

The means and SDs of all variables were derived from 60 valid executions. We calculated the Kolmogorov-Smirnov ($\alpha \leq .05$) and Levene ($\alpha \leq .10$) tests to confirm normal distribution and variance homogeneity (SPSS version 23.0; IBM Corp). Cohen *d* effect sizes were computed with 90% CIs[42] and interpreted as *large* ($\geq$0.8), *moderate* (0.8–0.5), *small* (0.5–0.2), or *negligible* (<0.2) to quantify whether the exercise variations (clusters of 3–4 exercises with and without shank inclination, additional load, and hip flexion) affected the kinetic and EMG variables.

All 20 analyzed NHE variations met the intended execution criteria without excessive DWA. The average shank inclination was 29.2° ± 1.2° for the inclined variations. The NHE variations demonstrated gradually increasing peak moments from 69% (zigzag pose) to 154% (inclined bent single-legged version) versus the standard NHE (Figure 3A; see Supplemental Table, available online at https://doi.org/10.4085/0010.22.S). We also observed considerable ranges for peak BFlh (15.3%–128.3% MVIC) and ST (25.7%–132.4% MVIC activation; Figure 3B and C; see Supplemental Table). The 30° of shank inclination and 5 kg of additional load elicited small to moderate effects on peak moments and peak BFlh and ST activation ($0.24 \leq d \leq 0.72$), whereas 90° of hip flexion largely affected all tested variables ($2.80 \leq d \leq 6.66$), especially peak hamstring activity (BFlh = −63% MVIC, ST = −55% MVIC; Figure 4). Half of the NHE variations (n = 10) showed similar ST-BFlh activations (<10% difference; Figure 5). Three exercises favored higher peak BFlh activation ($\geq$10% versus ST); 7 promoted peak ST activation (see Supplemental Table).

DISCUSSION

Characteristics of the Stepwise Progression to NHE

The main purpose of our exploratory case study was to investigate the kinetics, kinematics, and EMG activity of NHE variations (facilitations and intensifications) in 1 participant with a high level of NHE expertise to establish a scientifically evaluated stepwise progression. Based on the

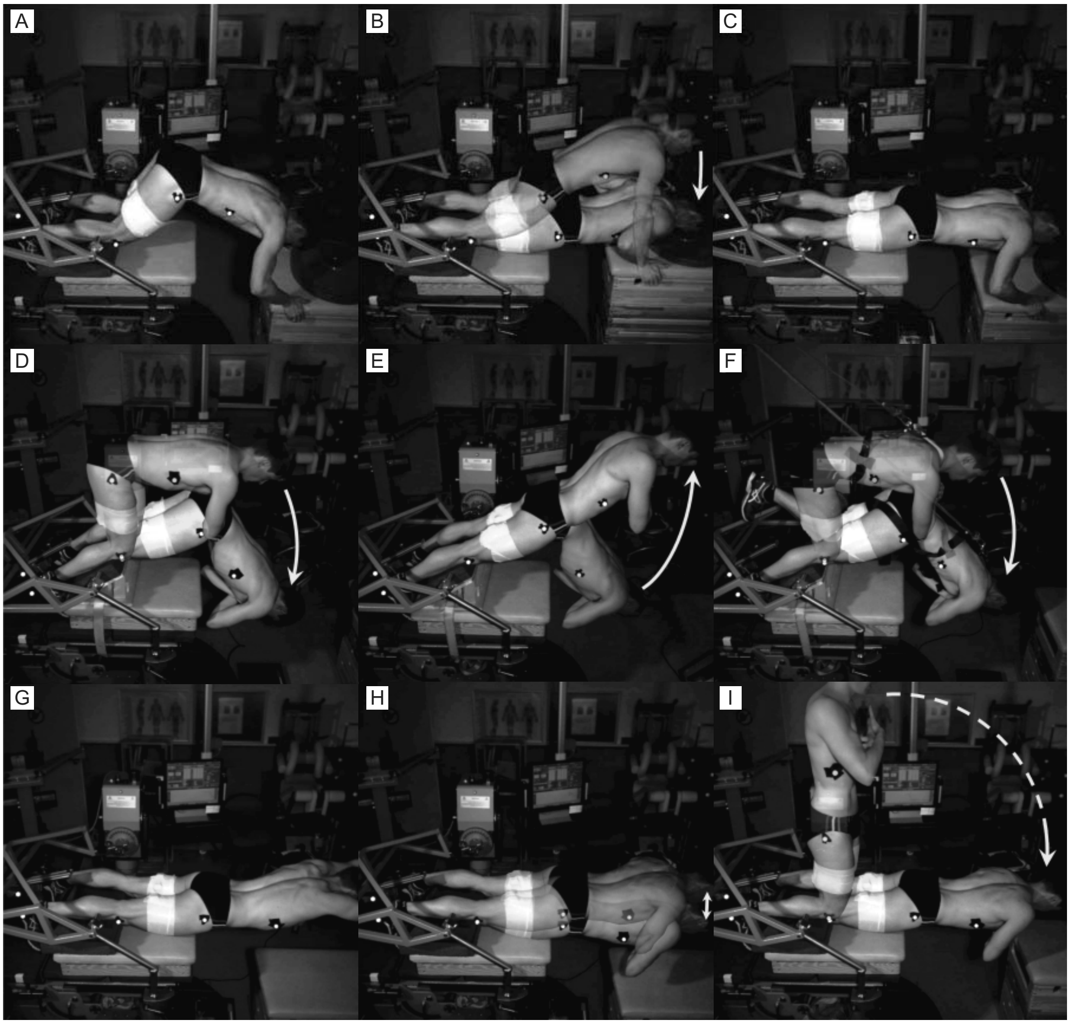

Figure 2. An exemplary selection of 9 Nordic hamstring exercise variations, out of 20 exercises of the presented stepwise progression model, which involved A–C, adapted activation; D–F, inclined; and G–I, leveled Nordic hamstring exercise. A, Zigzag activation. B, Guided final-stage activation. C, Nordic hamstring plank activation. D, Inclined bent version. E, Inclined Nordic glute raise. F, Inclined bent single-legged version (assisted). G, Extended Nordic hamstring pose. H, Bouncing Nordic hamstring plank. I, Loaded decelerated standard version.

collected data, a model of 6 progressive levels and 5 cutoff exercises (see Supplemental Table; 20 exercise variations in total) was established. The analyses confirmed the first hypothesis, with NHE peak moments almost linearly increasing across the progressive levels except for the adapted activations in level 1: from 69% (zigzag pose) to 154% (inclined bent single-legged version) versus a standard NHE (Figure 3A; see Supplemental Table). Consequently, a sensible clustering of the analyzed NHE variations into performance levels 2 through 6 was possible. Peak muscle activity of the BFlh (15.3%–128.3% MVIC) and ST (25.7%–132.4% MVIC) demonstrated a large gradation as well; however, their progressions were not linear but resembled an inverted U shape that peaked in level 4 (Figure 3B and C; see Supplemental Table). Thus, the available data supported the first hypothesis for peak muscle activity as well. Exercises that involve an adapted activation (Table) can be performed by everyone and at any desired intensity. Therefore, they constitute the first level of the model and were ranked with respect to their coordinative demands (from easy to difficult). We identified standardized cutoff exercises with peak moments that separated the distinctively clustered NHE performance levels. They predominantly involved isometric characteristics or implemented controlled settings that can be easily replicated in a standardized fashion (eg, protruding knee joints) without measurement tools.

A second main finding was that 90° of hip flexion largely affected all tested variables ($2.80 \leq d \leq 6.66$), whereas 30° of shank inclination and 5 kg of additional load elicited small to moderate effects on peak moments and peak BFlh and ST activation ($0.24 \leq d \leq 0.72$; Figure 4). The reduced peak hamstring activity induced by hip flexion confirmed evidence[27,35] obtained from participants at lower NHE performance levels. Flexing the hip joint reduces the moment arm of the resistance determining the gravitational acceleration of the center of mass of the body parts above the knee joint and thus decreases the moment of inertia of the center of mass. Concomitantly, the pelvic forward tilt that occurs with hip flexion elongates the fascicles of the hamstring muscles, which increases the contribution of the passive elements (eg, tendons, extracellular matrix, titin) to force generation.[39] Our data (Figure 1) supported an inverted

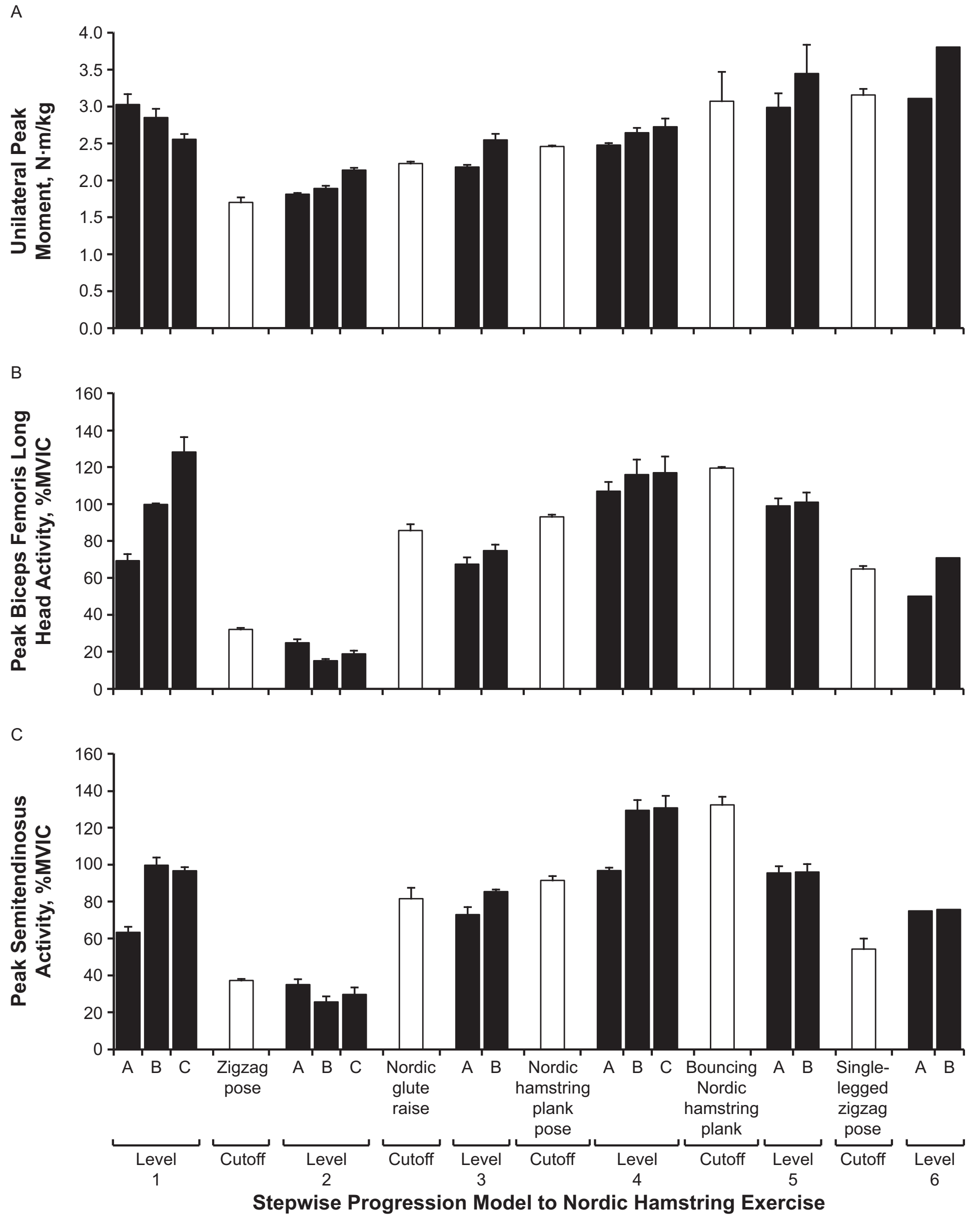

Figure 3. A, Kinetic; and B, C, electromyographic data (mean ± SD) of the 20 analyzed Nordic hamstring exercise (NHE) variations. The stepwise progression model, consisting of 6 progressive levels (black columns) and 5 cutoff exercises (white columns), revealed an almost linear increase in A, unilateral peak moments, whereas the peak activities of the B, biceps femoris long head and C, semitendinosus muscles resembled an inverted U shape that peaked in level 4 (see Supplemental Table). The characteristics of level 1 (adapted activation) should be considered because these exercises can be performed at any desired intensity. Abbreviation: MVIC, maximal voluntary isometric contraction.

U shape of muscle activity during maximal eccentric contractions.[43] When the initial velocity is increased[12] (eg, level 5), the moment is predominantly generated by the energy-absorbing characteristics of the passive elements.[38] Hence, these exercise variations will promote the spring mechanism of the musculotendinous units that are stretched by the highly activated muscles (approximately 100% MVIC).

Our results do not resolve the ongoing debate about the underlying activation patterns of the NHE[16–18] because of the differences across the NHE variations (Figure 4). The highest BFlh activation (128.3% ± 8.0%) emerged during the latter stages of the guided final-stage activation (level 1C; Figure 2B; see Supplemental Table). Given the guidance, it was feasible to superimpose active hip extension (ie, isometric gluteus activation) on the eccentric knee-flexion movement, which has been recently demonstrated to increase BFlh activation.[31] In addition, the NHE standard version performed by an expert elicited slightly and consistently higher BFlh activation during the entire movement (Figure 1). This finding supports the work of Bourne et al,[16] who demonstrated that the NHE elicited the highest BFlh activation among the 10 most common hamstring exercises. Therefore, our second hypothesis cannot be explicitly answered.

Challenges and Limitations

The main challenge will be to transfer the presented exercise variations into everyday training settings.[7,13,32,33] This can be realized using wall bars, doorway pull-up bars, or any other solid and rigid horizontal object.[37] Appropriate

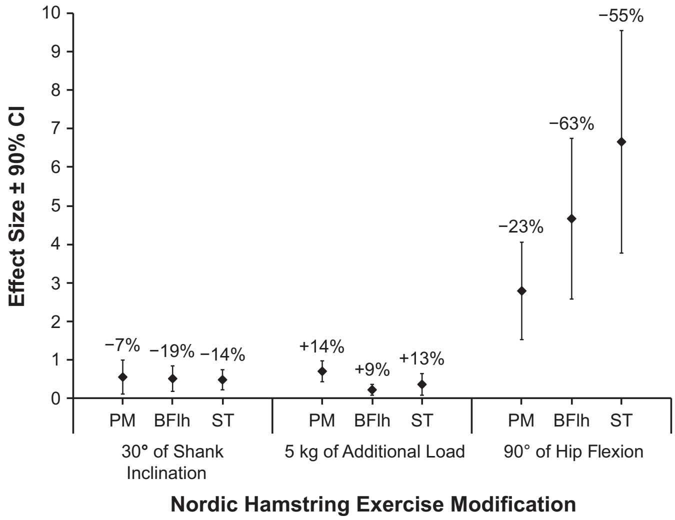

Figure 4. The clustered effect sizes of Nordic hamstring exercise modifications and their mean percentage change in kinetic and electromyographic variables (see Supplemental Table). Positive values indicate higher values when the modification is applied and vice versa. Shank inclination (exercise pairs: level 2B, level 3A, and NGR vs level 2A, NHP, and level 4A) and additional load (exercise pairs: level 2B, level 3A, NHP, and level 5A vs levels 2C, 3B, 4C, 5B) elicited small to moderate effects, whereas hip flexion (exercise pairs: levels 2A, 2B, and 2C vs levels 3A, 3B, and 4A) largely affected all tested parameters, especially muscle activity. Abbreviations: BFlh, biceps femoris long head muscle; NGR, Nordic glute raise; NHP, Nordic hamstring plank; PM, peak moment; ST, semitendinosus muscle.

kneeling height and shank inclination achieved using wedges enable bent and inclined NHE variations. In the future, portable training devices will allow for varied, versatile, and progressive hamstring strengthening. The analyzed NHE variations involved controlled movements. A supramaximal stress is placed on the muscle-tendon unit only if the knee angular velocity inevitably increases at the end of the knee ROM ("break point" at DWA). This might elicit the full potential and benefit of the NHE by enlarging the "muscle's safe operating range."[32] Performing all variations in a supramaximal manner would have caused excessive neuromuscular fatigue and delayed onset of muscular soreness. The effect sizes for the different modifications should be interpreted as effects in the different NHE variations for the single participant. Further investigations are needed to verify the observed effects in a broader population.

Future Directions in Research Exploration

In future studies, researchers should apply the presented NHE variations in heterogeneous groups (age, sex, body mass, height) in different training contexts (eg, elite, recreational, rehabilitative) to quantify interindividual differences in execution quality and performance level. This model should be implemented in longitudinal studies to gradually adapt the exercise selection to their participants' individual capacities. Thus, authors should evaluate whether the presented stepwise progression to the NHE makes the known prophylactic benefits more accessible to a broader population and preserves or enhances the risk-reduction evidence. Assisted NHE executions are favorable for inexperienced athletes or patients[28,32–34] to guarantee a high muscle

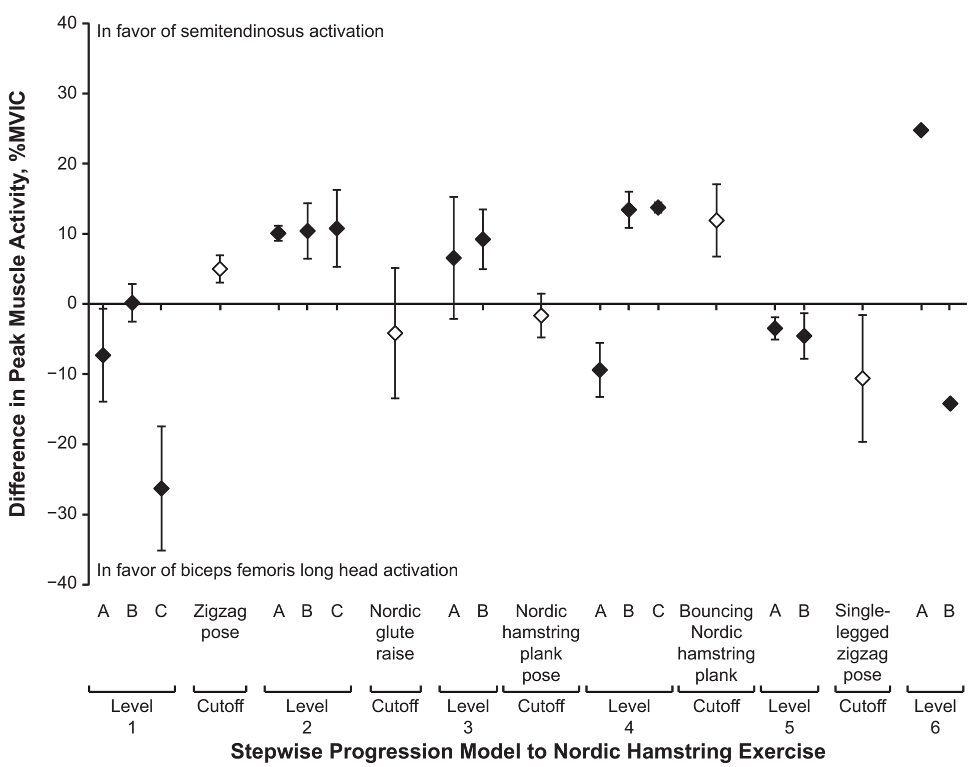

Figure 5. Differences in peak muscle activity (mean ± SD) during the 20 analyzed Nordic hamstring exercise variations (black diamonds, progressive levels; white diamonds, cutoff exercises; see Supplemental Table) emphasizing which exercises demonstrated higher activation of the biceps femoris long head or semitendinosus muscle. Single-legged exercises were executed and evaluated once. Abbreviation: MVIC, maximal voluntary isometric contraction.

activation and a certain time under tension at extended knee angles during NHE execution (approximately 0°–30° knee flexion)[20–22,25] and to promote muscle-tendon adaptations at longer hamstring lengths[3,26,30] according to the length-at-use and contraction-mode hypotheses.[23,24] Controlled unassisted, full-ROM NHE execution is recommended and appropriate to provide high-intensity exercise of the desired joint configuration only if the physical level of the athlete or patient is adequate.[2,5,28] In future NHE examinations, researchers should focus on high-quality and high-intensity exercises to elicit the desired neuromuscular and architectural changes[3,4,36,44] that might be sustained over several weeks to a couple of months.[5] Practical guidelines for high-quality NHE assessments and interventions were recently introduced with special regard to execution modalities and methodologic aspects.[37] To quantify valid forces, moments, or both during the NHE, investigators should accurately determine the force contact point.[45] Furthermore, the contributions of muscles other than the hamstring (eg, gastrocnemius, sartorius, and gracilis) should be determined.[26]

CLINICAL BOTTOM LINE

This case report introduced a stepwise progression to the demanding NHE that incorporates several new exercise variations to gradually modulate loading of the knee flexors. The data from an elite NHE performer provide comprehensive insights into the kinetic, kinematic, and EMG modifications that can be realized via hip flexion (large effects) and shank inclination and additional load (both small to moderate effects). When this model is applied in heterogeneous groups with different sport backgrounds and physical capacities, it will potentially be a powerful patient-centered guideline for treating musculoskeletal conditions[9,10,14] and individualizing the NHE training regimen.[37]

The progression model provides exercise variations that are well adapted to the specific needs and capacities of individuals, which is essential for beginners and young, injured, or weaker people.[6,7,36,37] Attention should be directed to interindividual differences of anthropometrics and physical capacities that will inevitably lead to slightly diverging individual ratings of exercise difficulty. By using the 5 cutoff exercises, athletes can be easily classified into 1 of the 6 progressive levels without any measurements—provided that the knee joints protrude from the kneeling pad, because this affects the generated moments and thereby the perceived exercise difficulty. The advantage of level 1 is that it can be performed at any desired intensity, which presents several possible applications (eg, warm-up, preactivation, rehabilitation). Practitioners and scientists should be careful that they do not compensate for insufficient exercise quality or performance or experience levels of NHE execution by increasing the exercise volume, as unfortunately suggested by the Fédération Internationale de Football Association (FIFA) 11+ program.[7,13] Instead, they should highlight the well-documented demands of a single NHE[2,21,22,26,35] to reduce overloading by implementing appropriate facilitations (eg, shank inclination, hip flexion) or exercise intensifications (eg, additional load, deceleration). By following the presented guidelines and further varying this structure, multiple sublevels are feasible, and every individual can gradually progress knee-flexor strength capacities from "zero to hero."

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SUPPLEMENTAL MATERIAL

Supplemental Table.

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