Mar 31st, 10:30 AM - 12:30 PM

# ES-03 The Effects of a Warmup Protocol Involving the Nordic Hamstring Exercise on Vertical Squat Jump Performance and Peak Muscular Activation

Reagan Hunter
*Lander University*

Jeff Barfield
*Lander University*

# THE EFFECTS OF A WARMUP PROTOCOL INVOLVING THE NORDIC HAMSTRING EXERCISE ON VERTICAL SQUAT JUMP PERFORMANCE AND PEAK MUSCULAR ACTIVATION

Reagan Hunter and Jeff Barfield Ph.D.
Lander University Greenwood, SC 29649

## INTRODUCTION

Vertical jumping is one of the most popular ways of assessing athleticism and power output of the lower body in both professional and recreational sport settings. Therefore, having access to an appropriate warmup protocol for enhancing this skill and the power output associated with it is essential for athletes whose success depends on the ability to perform it. Current literature demonstrates similar posterior kinetic chain muscle engagement during the vertical squat jump and during an exercise called the Nordic Hamstring Curl. The literature additionally demonstrates the exercise's significant effects on strength and athleticism when used in long-term training programs. However, no research has been conducted on the potential acute effects on athletic performance this exercise may yield when used as a warmup protocol.

## METHODS

Population
- 5 Active College Age individuals

Surface Electromyography Sensor Placement
- Bilateral Biceps Femoris
- Bilateral Semitendinosus
- Bilateral Gluteus Maximus
- Bilateral Erector Spinae

Warmup Protocol
- 10 minutes on the stationary bike
- 5 vertical squat jumps with a 10-pound dumbbell in each hand
- Dynamic stretching
- 3 sets of 5 reps of the partner Nordic Hamstring Curl to maximal effort with 3 min rest between sets (not included in the control protocol)

Data Collected
- 5 Vertical squat jumps on a force plate
  - Flight Time
  - Peak EMG activity

Repeated measures randomized control design
- intervention and control protocols were performed one week apart.

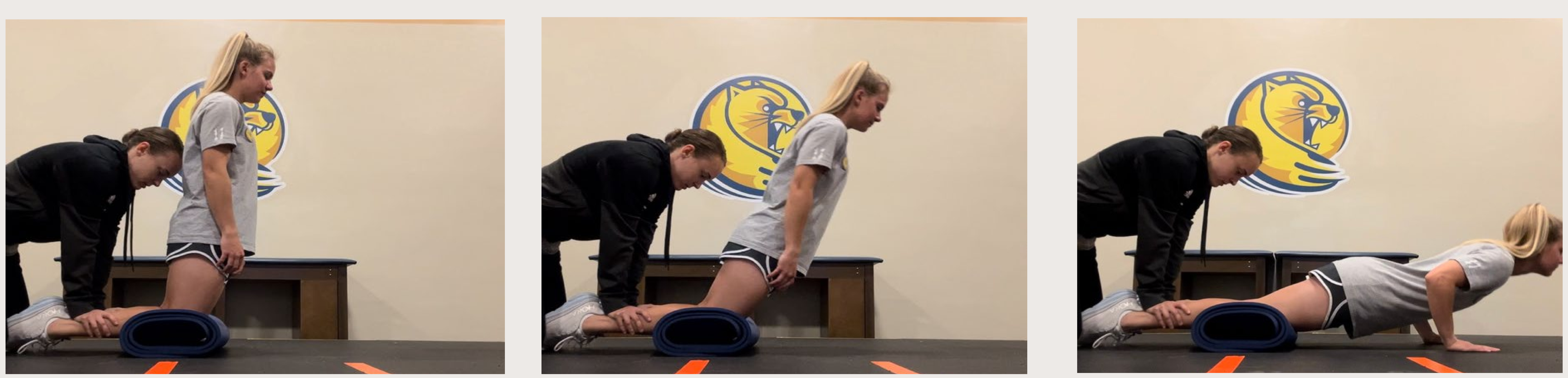

Fig. 1. Steps of the Nordic Hamstring Curl

## PURPOSE

The purpose of this study was to explore the effects of a warmup protocol involving the Nordic Hamstring Curl on flight time and peak EMG activity of the bilateral biceps femoris, semitendinosus, erector spinae, and gluteus maximus muscles during the vertical squat jump in an active college aged population.

## DATA

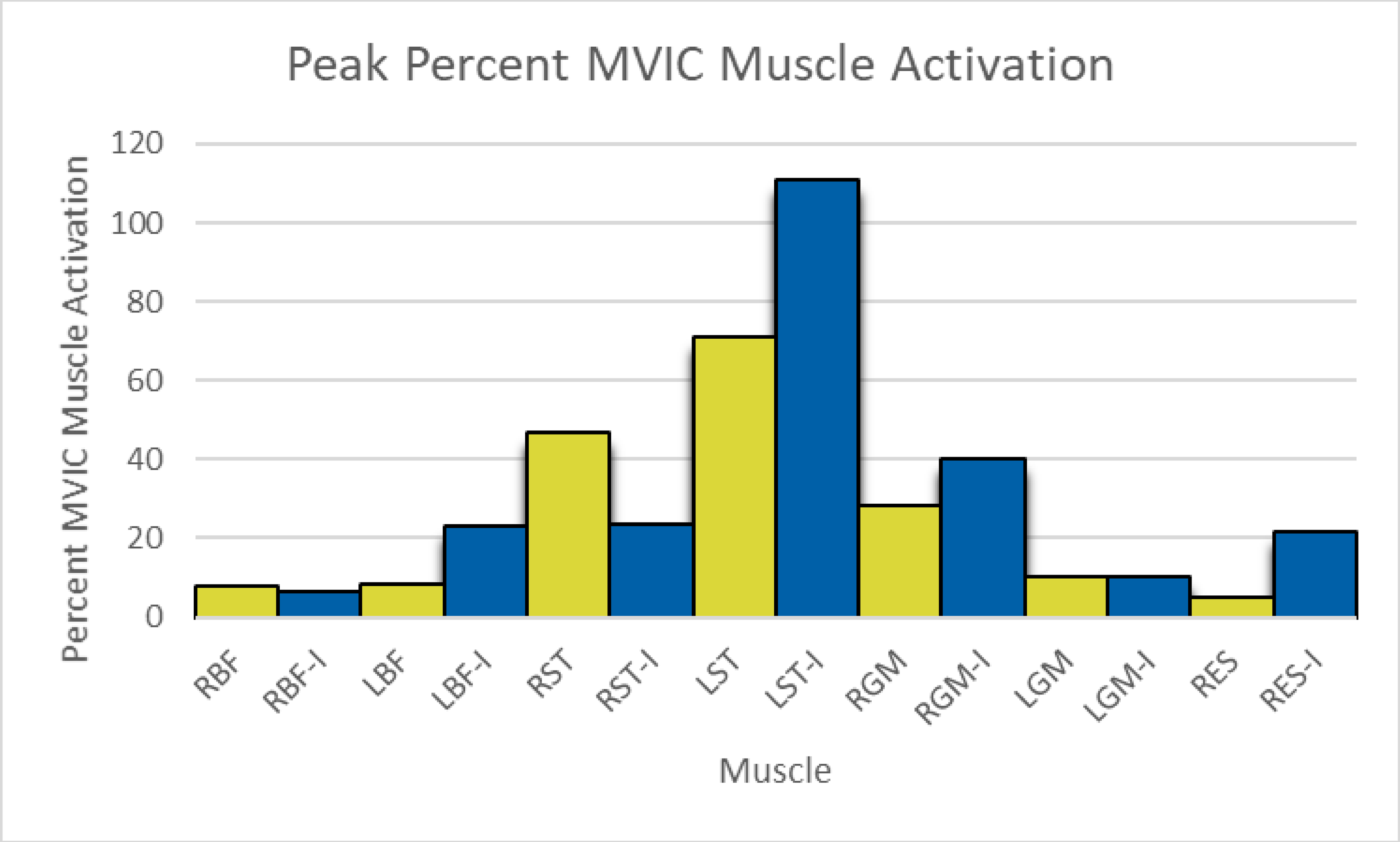


Fig. 2. Peak Percent MVIC Muscle Activation during Vertical Jump for the following musculature: RBF – Right Biceps Femoris, LBF – Left Biceps Femoris, RST – Right Semitendinosus, LST – Left Semitendinosus, RGM – Right Gluteus Maximus, LGM – Left Gluteus Maximus, RES – Right Erector Spinae. I indicates intervention trial muscle activation.

## RESULTS

Shapiro-Wilkes test revealed normal data. Paired student t-test revealed no significant difference in peak muscle activation of the bilateral biceps femoris, semitendinosus, erector spinae, and gluteus maximus between the two trials. A paired student t-test also revealed no significant difference in flight time between trials ($t$= -4.94 e-4, $p$ = 1.00).

## CONCLUSION

While our hypothesis that the Nordic hamstring exercise would elicit increased muscle activation of the bilateral biceps femoris, semitendinosus, gluteus maximus, and erector spinae muscles during the vertical jump was rejected, descriptive statistics of this pilot study suggest that future research should consider pelvic kinematics during the vertical jump to gain a complete understanding of the effects of the Nordic hamstring exercise as a warm-up exercise. Considering the biarticulate nature of the musculature tested, participants could have adapted by altering pelvic kinematics thus affecting muscle activation. No detrimental effects were observed for using the Nordic hamstring exercise as part of a warm-up protocol during this pilot study.

## REFERENCES

1. Bobbert, M. (1996). The role of the hamstrings in human vertical jumping. IEEE Xplore.
2. Cleather, D. J. (2018, July 20). An important role of the biarticular hamstrings is to exert internal/external rotation moments on the tibia during vertical jumping. Journal of Theoretical Biology.
3. Ferri-Caruana, A., Mollà-Casanova, S., Baquedano-Moreno, M., & Serra-Añó, P. (2022, April 27). Electromyographic activity of posterior kinetic chain muscles during hamstring strengthening exercises. Physical Therapy in Sport.
4. Holt, B., & Lambourne, K. (2008). The impact of different warm-up protocols on vertical jump... : The Journal of Strength & Conditioning Research. LWW.
5. Iga, J., Fruer, C., Deighan, M., Croix, M., & James, D. (2012). 'nordic' hamstrings exercise - engagement characteristics and training responses. International journal of sports medicine.
6. Phillips, W., Burkett, L., & Ziuraitis, J. (2005). The best warm-up for the vertical jump in college-age athletic men. Journal of strength and conditioning.

# The Effects of a Warmup Protocol Involving the Nordic Hamstring Exercise on Vertical Squat Jump Performance and Muscular Activation of the Bilateral Semitendinosus, Biceps Femoris, Gluteus Maximus, and Erector Spinae Muscles: A Repeated Measures Randomized Controlled Trial

Reagan Hunter

Lander University

October 28, 2022

## 2. Literature Review

### 2.1 General Information

#### 2.1.1 The Nordic Hamstring Exercise

The Nordic Hamstring Exercise (NHE) is a highly effective strengthening exercise containing an eccentric and concentric phase. It is performed from a starting kneeling position with 90° knee flexion and 0° hip flexion. The eccentric portion is performed by extending the knees with the ankles secured down to slowly lower one's neutral trunk and thighs to the ground, and the concentric portion involves raising the trunk and thighs back up to the original position. Modified versions may include catching oneself in a pushup position and allowing the hands to assist in propelling the body back upward by pushing against the ground.

Its origins may go back to George Herbert Taylor's 1860 book *Exposition of the Swedish Movement Cure* which was inspired by the Ling gymnastics system and referred to the NHE as the "wing kneeling/knee stretching exercise" (Heffernan, 2021). However, this exercise was popularized by a 2004 study comparing the effects of a training program with the NHE to a training program with traditional hamstring curls on eccentric hamstring strength in 21 well-trained soccer players (Mjølsnes, et al., 2004). The NHE group experienced significant increases in eccentric hamstring torque, isometric hamstring strength, and hamstrings:quadriceps ratio. The hamstring curl group experienced no significant changes.

#### 2.1.2 The Vertical Squat Jump: A Test of Muscular Power Output

The vertical squat jump is an excellent test of power generation of the Biceps Femoris (BF) muscles. A 2013 study was conducted to investigate EMG activity of the BF in the concentric and eccentric phases of a counter movement jump, squat jump, and landing task in twelve female volleyball players. The ANOVA test showed significantly lower activation of the biceps femoris in both the concentric and eccentric phases of the countermovement jump when compared to the landing task and the squat jump (Padulo et al., 2013). Both the CMJ and SJ are excellent methods for testing power output and athleticism, but the SJ is a better indicator of raw muscular power output, while the CMJ "reflects the ability to utilize the stretch-shortening cycle" (Kozinc et al., 2021).

## 2.2 Specific Muscular Engagement in the Vertical Squat Jump

### 2.2.1 The Biceps Femoris as a Hip Extensor during the Concentric Phase of the VSJ

A 1996 study was conducted to explain the differences in the roles of biceps femoris and semitendinosus muscles in the vertical squat jump. During maximum-height squat jumping, the ST exhibited a bi-phasic EMG pattern, and the BF exhibited a mono-phasic pattern. This demonstrates how the two different hamstring muscles perform different roles during squat jumping. The mono-phasic EMG pattern of the BF indicates its role as a hip extensor during the concentric takeoff phase of the jump that results in triple extension. This study was conducted using both an experimental study and forward dynamic simulation model. In the experimental study, kinematics, ground reaction forces, and EMG sensors were used. The simulation model used four rigid segments and the same seven muscles of which EMG activity was measured in the experimental study to create a Hill-type muscle model which was individualized for each subject (Bobbert, 1996).

### 2.2.2 Preferential Recruitment of the Semitendinosus as a Knee Flexor during the Eccentric Phase of the VSJ

The bi-phasic EMG pattern of the ST indicates its role in initiating the jump in the eccentric phase and contributing to power generation in the concentric phase. The ST initiates the jump because it has a larger moment arm than the BF at the knee and, therefore, "produces a larger knee flexion moment, and may cause a forward-downward acceleration of the center of mass rather than a forward-upward acceleration" (Bobbert, 1996). This resulting delay of knee extension "allows the knee extensors to build up force before they start to shorten, rather than during shortening, thereby increasing muscle work and jump height (Bobbert, 1996).

### 2.2.3 Biarticular Hamstrings as Both Knee Flexors and Internal/External Rotators during the VSJ

A study was conducted to evaluate the internal and external moment arms of the biarticular knee muscles exerting forces on the proximal tibias in twelve trained males during vertical jumping trials. This was accomplished using retro-reflective markers with an optical motion capture system and a model of the musculoskeletal geometry of the lower limb to calculate joint contact forces and use those analyses to derive the moments. This allowed the internal/external rotation arms of the muscles to be quantified during vertical jumping. The model was also used to estimate forces in all three anatomical planes of motion during vertical jumps. It was found that the biceps femoris and tensor fascia latae were external rotators of the tibia, and the semitendinosus, semimembranosus, sartorius, gracilis, popliteus, and patellar tendon were internal rotators of the tibia. The internal/external rotation moments that the biarticular hamstrings exerted on the tibia displayed magnitudes similar to those of the flexion moments they exerted on the tibia in the sagittal plane. This provides evidence that "an important role of the biarticular muscles is thus to create rotational stability of the tibia in the transverse plane, and that there are a number of advantages to the biarticular muscles performing this role" (Cleather, 2018).

### 2.2.4 The Gluteus Maximus Muscles in the VSJ

An observational study on force development in vertical static squat jumping conducted using sEMG sensors, a VICON high speed video analysis system, and force plates found that the Gluteus Maximus contributes to the hip extension joint moment that allows for the concentric take off phase of the jump. The BF and ST are ideally suited to increase the moment of the hip relative to the moment of the knee by generating a forward acceleration of the center of mass which not only increases the extension moment at the hip joint but also reduces the extension moment at the knee joint. However, the Gmax is able to contribute to this hip extension joint moment without simultaneously reducing the knee's extension moment. It was found that while the ST, BF, and Gmax all three contribute to the moment of the hip, the Gmax contributes the most to upward vertical acceleration of the center of mass that occurs during takeoff (Bobbert & van Zandwijk, 1999).

### 2.2.5 The Erector Spinae Muscles in the VSJ

An observational study was conducted on eight male athletes to determine how lumbar spine extension and erector spinae muscle activation influences vertical squat jump height. EMG activity of the erector spinae muscles was recorded during the maximal squat jumps. Reflective markers and a camera were used to capture the motion, and a computer simulation was used to simulate maximal squat jumping with differing spine extensions and ES strengths. These indicated lower jump heights for squat jumps without trunk extension. They also indicated decreased jump heights when the ES muscle was not taken into consideration in the model. The study concluded that "the erector spinae should be considered as a trunk extensor, which enables one to enhance total muscle work and consequently vertical jump height" (Blache & Monteil, 2014).

Another 2014 study conducted by Blache & Monteil evaluated the effects of initial spine flexion and maximal isometric force of the ES on maximal vertical squat jump height. The same type of 2D simulation model of the musculoskeletal system was used to test seven different initial flexions of the thorax-head-arm segment and five maximal isometric forces of the ES in thirty-five different simulated squat jumps. The study concluded that an "increase in the initial flexion of the 'thorax–head–arm' segment and in the maximal isometric force of the erector spinae enables an increase in maximal vertical jump height during maximal squat jumping" (Blache & Monteil, 2014).

### 2.3.1 Current Warmup Protocols for Vertical Jumping

Current warmups proven effective for vertical jumping include cardiovascular warmup protocols, dynamic warmup protocols, static stretching protocols, and dynamic flexibility protocols. However, a 2008 study conducted on sixty-four male Division I football players indicated that a static stretching warmup produced significantly lower increases in vertical jump height than the other three protocols (Holt & Lambourne, 2008). Another study found that "utilizing a weighted resistance warm-up produces the greatest benefit when performing the vertical jump test" (Burkett, et al., 2005) when compared to a submaximal jump warmup, a stretching warmup, and no warmup. However, a study to assess the effect of a static stretching, medicine-ball, and mini-band warmup on athletic ability test performances was conducted on 24 NCAA Division I women's soccer players and found that none of the three warmups had significant effects on vertical jump test performances (Christensen et al., 2020).

### 2.3.2 Current Training Programs for Vertical Jumping

Current training programs for vertical jump performance enhancement typically focus on plyometrics and strength training of the gluteal and quadriceps muscles. A meta-analysis of randomised and non-randomised controlled trials evaluated the effect of plyometric training on the squat jump (SJ), countermovement jump (CMJ), countermovement jump with arm swing (CMJA), and drop jump (DJ) and found that plyometric training provides statistically significant improvements in vertical jump height (Markovic, 2007). Training protocols consisting of exercises that activate the gluteus maximus and medius muscles are effective in improving vertical jump performance in amateur athletes (Gallego-Izquierdo et al., 2020). It has been shown that beginners can increase vertical jump performance through basic strength training exercises such as squats but that "elite strength training athletes may not record VJ improvements if they only perform general strength exercises such as squats and very heavy weightlifting exercises" (Baker, 1996). Current strength training programs and warmup protocols for vertical jumping often neglect focusing specifically on the hamstrings or erector spinae muscles.

**2.4 Specific Muscle Engagement and Adaptations Caused by the NHE**

A 2022 cross sectional study (Ferri-Caruana et al.) conducted on twenty-four athletes compared the muscular activation of the BF, ST, Gmax, and ES muscles in four different eccentric hamstring exercises including the NHE, Russian belt exercise, a glider exercise, and lying kicks. The NHE and lying kicks showed overall higher maximum EMG activation than the other two exercises. Maximum activation of the BF and ST muscles was significantly higher in the NHE and lying kicks compared to the glider and Russian belt exercises (Ferri-Caruana et al., 2022).

**2.4.1 The Biceps Femoris Muscles in the NHE**

A cross sectional study conducted to determine the presence of eccentric hamstring contractions during the NHE in active male participants new to the exercise involved imaging muscle fascicle lengths of the BF during the exercise. This was accomplished by using two-dimensional B-mode ultrasound imaging of the left BF in addition to measuring external reaction force, knee angle, and sEMG activity of the left BF. Two ultrasound tracking algorithms were used to determine changes in the muscle fascicle lengths of the BF muscles during maximal voluntary contraction trials of the NHE. The ultrasound tracking algorithms indicated significant net BF muscle fascicle lengthening as well as positive mean fascicle velocity during peak force in the NHE. This occurred during positive knee extension velocity, indicating that the NHE does cause predominantly eccentric action in the biceps femoris muscles which may in turn contribute to increases in resting biceps femoris muscle fascicle lengths (Raiteri et al., 2021). The study conducted by Narouie et al. confirms that BF activity during the NHE is very high (2018).

Furthermore, a 2018 study conducted by Presland, et al., found that both high and low volume training with the NHE caused increases in the resting BF long head fascicle lengths and in eccentric knee flexor strength. This clinical trial study was conducted on twenty recreationally active males and involved both groups completing a two-week training period of the eccentric phase of the NHE and was followed by a four-week period of high-volume training of the exercise for one group and low volume training for the other group. This further emphasizes the enhanced length tension relationship of the bilateral BF muscles that the NHE promotes. "These architectural adaptations reverted to baseline levels within two weeks after ceasing training, but eccentric strength was maintained for at least four weeks" (Presland, et al., 2018).

**2.4.2 The Semitendinosus Muscles in the NHE**

A two-part cross-sectional study conducted on 24 recreationally active males found that hip-extension exercises “selectively activate the long hamstrings, and the Nordic exercise preferentially recruits the semitendinosus” (Bourne et al., 2017). Part one of the study measured the ratios of biceps femoris to semitendinosus and semimembranosus normalized EMG activity during both the concentric and eccentric portions of ten popular strength training exercises. Part two of the study took the 45-degree hip extension exercise which demonstrated the largest BF to medial hamstring (MH) ratio and the NHE which demonstrated the smallest BF to MH ratio and measured the hamstring spatial pattern activations during those two exercises using a functional MRI. Although the NHE demonstrated a selective activation of the ST, resulting in a small BF to MH ratio, the nEMG activity of the BF during the eccentric phase of this exercise was higher than the nEMG activity of the BF during the eccentric phase of any of the other exercises. This indicates that, although the NHE does preferentially recruit the semitendinosus more heavily than the BF, its overall recruitment of all three hamstring muscles is very high compared to other hamstring exercises (Bourne et al., 2017). The study conducted by Narouie et al. “concur[s] the researchers that ST muscle is preferably activated during NHE” (2018).

The cross-sectional study that examined the ten male subjects’ electromyography of fifteen different muscles during the NHE found that the mean EMG activity level of the ST muscle in both the downward and upward phases of the NHE was the greatest out of all muscles measured, and the BF activity closely followed. These activity levels were calculated using the Paired t-test on variance in the downward and upward motions (Narouei et al., 2018).

**2.4.3 The Gluteus Maximus Muscles in the NHE**

In the above cross-sectional study (Narouei et al., 2018) that measured the EMG activity of fifteen muscles during the NHE, the ratio of gluteus maximus to erector spinae activity

(Gmax/ES ratio) was additionally measured and calculated using Pearson correlation analyses. It was found that this ratio increased with decreasing knee extension angle during the upward motion. The ratio decreased with increasing knee extension angle during the downward motion. This indicates the importance of the role of the Gmax for pelvis stabilization throughout the entire exercise and its especially important role in the concentric phase of the exercise in which the subjects move upward and return to the starting kneeling position. This proper pelvis stabilization allows for maximum hamstring performance and reduces the risk of over compensatory mechanisms of the hamstrings (Narouei et al., 2018).

Additionally, a 2022 cross-sectional study conducted on fifteen trained females measured the EMG muscle activation patterns of the BF and Gmax muscles during the Romanian deadlift (RDL), Step-up, prone leg curl, 45-degree hip extension, cable kickback, and NHE. The Romanian deadlift, step-up, and 45-degrees hip extension exercises resulted in higher Gmax activation than the NHE, since hip extension is the primary action in those exercises. The Gmax is the primary hip extensor muscle, and the BF possesses a secondary action of hip extension, so those results are to be expected. However, in the NH and leg curl exercises where the primary actions occurring are knee flexion and extension, it was found that the Nordic Hamstring Exercise resulted in significantly greater muscle activation than the leg curl (Stevens, et al., 2022).

### 2.4.4 The Erector Spinae Muscles in the NHE

Narouei et al.'s 2018 study's results indicate the importance of the erector spinae muscles as knee extension angle increased in the lowering phase of the exercise as indicated by the smaller Gmax/ES activation ratio in this phase. The ES muscles are equally as important as the Gmax muscles in firming a strong base of stability in the trunk during the exercise. Therefore, the greater the activation of both the Gmax and ES muscles, the better foundation the hamstrings will have to respectively create both the necessary concentric and eccentric contractions during the NHE (Narouei et al., 2018).

A 2019 study was conducted with the purpose of measuring EMG activity of the BF, ST, Gmax, ES, and gastrocnemius muscles in eighteen adults during six different variations of the NHE where hip angles were altered to cause these variations. In regard to erector spinae activity, it was found that the peak EMG activity significantly decreased in all of the modified variations of the exercise when compared to the standard NHE (Šarabon et al., 2019).

### 2.4.5 High ST Activation in the NHE and Preferential ST Recruitment in VSJ

As shown above, Bourne et al.'s 2017 study demonstrated that "the Nordic exercise preferentially recruits the semitendinosus", and Narouie et al.'s 2018 study concurs these results by finding that the mean EMG activity level of the ST in both the downward and upward phases of the NHE was the greatest out of all muscles measured (Narouie et al., 2018). Moreover, Bobbert studied the significance of the bi-phasic EMG pattern's indication of the ST's role in initiating the squat jump by allowing "the knee extensors to build up force before they start to shorten, rather than during shortening, thereby increasing muscle work and jump height (Bobbert, 1996).

Since these results indicate the ST's primary responsibility for eccentric knee flexion and, therefore, knee positioning before initiation of the squat jump, performing an exercise like the NHE which preferentially recruits the ST muscle has potential to yield significant results on power output and jump height. Additionally, the NHE's recruitment of the BF (Raiteri et al., 2021) and improvement of its length-tension relationship (Presland, et al., 2018) has potential to yield significant improvements in the concentric take-off phase of the squat jump.

## 2.5 General Benefits of the NHE

### 2.5.1 Athletic Performance Enhancement

A 2018 clinical trial found significant differences in improvements in hamstring muscle flexibility, strength, and endurance between an experimental group completing five weeks of NHE training combined with a conventional exercise program and a control group completing only the conventional exercise program (Babu et al., 2018). Additionally, a 2012 clinical trial evaluating changes in the eccentric strength of the knee flexors after a 4-week NHE training program found significant improvements in peak knee flexor torque in the experimental group compared to the control group (Iga et al., 2012). The same study also examined hamstring neuromuscular activation characteristics during the NHE and found that the bilateral hamstrings were identically engaged during the NHE, yielding gains in eccentric peak torque of the hamstrings in both limbs simultaneously and allowing them to withstand greater amounts of forces when stretched, which can lead to reduced injury risk (Iga et al., 2012).

A single blinded randomized control trial study on fourteen male athletes investigated changes in eccentric isokinetic hamstring strength, 10m sprint performance, and change of direction performance (COD) following a six-week NHE intervention and following a three-week detraining period. For the outcomes measured immediately following the intervention, significant differences were found in the NHE group for all three measured outcomes compared to the "do-as-usual" control group. Improvements in the COD and sprint performances were found to be maintained following the detraining period. It was concluded that these findings indicate "it may be possible to manipulate implementation of the NHC as both an injury prevention exercise whilst simultaneously improving functional performance" (Siddle, et al., 2018).

### 2.5.2 Injury prevention

The NHE is known as one of the best hamstring injury prevention exercises (Farahbakhsh et al., 2020). A systematic review and meta-analysis were conducted on 8459 athletes across fifteen different studies with dependent variables of hamstring injury rates and independent variables training of the NHE. The study found that the NHE reduces hamstring injury rate by up to 51% across multiple sports in prospective and intervention studies (van Dyk et al., 2019).

## 2.6 Acute Effectiveness of the NHE

As stated above, Ferri-Caruana et al.'s 2022 cross sectional study found that the NHE has overall higher maximum EMG activation of posterior kinetic chain muscles including the BF, ST, Gmax, and ES when compared to the glider and Russian belt exercises. Activation of the BF and ST muscles was significantly higher in the NHE compared to the glider and Russian belt exercises (Ferri-Caruana et al., 2022).

A small repeated measures study with thirty three participants was conducted to compare peak hamstring activity between the standard NHE, modified NHE, and glider exercise. It found that hamstring activity during the modified NHE was significantly higher than that of the glider. Hamstring activity during the NHE was significantly higher than the modified NHE and the glider (Marušič & Šarabon, 2020).

A study was conducted to compare the EMG hamstring muscle activity in the BF, ST, and semimembranosus (SM) muscles in twelve male athletes during seven hamstrings exercises (performed in a randomized order) to the EMG muscular activity produced during maximal sprints. Exercises included the laying hamstring kick, the standing hamstring kick, the NHE, the NHE with return, the NHE with a bump, hamstring cranes without return, and hamstring cranes with return. EMG activity for each exercise was expressed as a percentage of the maximum activation produced while sprinting. Maximum EMG activity for the ST and BF during sprinting was significantly higher compared to all seven exercises. Maximum EMG activity for the SM during sprinting was significantly higher compared to all of the exercises except for the laying kick which had significantly higher SM activity compared to the standing kick and cranes exercises. All three NHE variations had significantly higher EMG activity of the BF and ST muscles compared to the crane exercises. The laying kick, the NHE, and variations of the NHE were found to produce the highest muscle activations of all the exercises. The joint angles at which maximal hamstring EMG activity occurred were also measured using a 3D motion capture system, and the angles of highest EMG activity during the sprints most closely matched the angles at which they occurred in the NHE and its variations. The joint angles of maximal EMG activation of the other exercises were not similar to those measured during sprinting (van den Tillaar, et al., 2017).

A crossover design study (Mellor, 2020) was conducted on sixteen male academy footballers in which the players first completed a control period of six weeks of soccer specific training and then underwent a six-week intervention period that involved adding the assisted NHE as a pre-activation warm up. The assisted NHE was chosen over the NHE to allow for guaranteed full range of motion and to minimize potential soreness experienced by the full-time players. The study’s objective was to assess the assisted NHE’s effect on eccentric hamstring strength, contractile properties, 10 m sprint performance, CMJ performance, and SJ performance. After the intervention period, increases in eccentric strength occurred in both limbs of the players, but only those in the right limbs were statistically significant. There were no statistically significant changes in the contractile properties of the muscles. However, significant changes occurred in the 10 m sprint, CMJ, and SJ. Mellor therefore hypothesized that although the assisted NHE may not have provided adequate stimulation to cause significant eccentric strength and contractile increases in both limbs, changes occurring in the length tension relationship of the hamstrings at longer lengths likely accounted for the statistically significant increases in the sprint and jump performances (Mellor, 2020). This is one of few studies to focus on the NHE's direct correlation to vertical squat jump performance. Even though the intervention was performed over a six-week time period, it was administered in the form of an activation warmup for the players' soccer training sessions rather than in the form of a rigorous strength training protocol.

The literature demonstrates a clear relationship between the NHE and recruitment of the semitendinosus, biceps femoris, erector spinae, and gluteus maximus muscles and between the NHE and improvements in injury rates and eccentric strength after the completion of training programs that implement this exercise. Additionally, studies indicate the important role of the recruitment of these posterior kinetic chain (PKC) muscles in vertical squat jump performance. However, there are large gaps in the literature pertaining to correlation between this exercise and its acute effects on athletic performance when utilized as a warmup protocol for athleticism tests like the VSJ which heavily engages the PKC muscles of interest. The only study (Mellor, 2020) that implemented it into a warmup protocol as an activation exercise utilized a modified version of the exercise and still had a six-week long intervention where it is was used as an activation exercise for soccer training sessions rather than for the VSJ which was one of the measured outcome variables after the six weeks. Additionally, current training and warmup protocols for vertical jumping do not put enough emphasis on the hamstring or erector spinae muscles. Therefore, further experimentation needs to focus on the NHE's acute effects on athletic performance tests such as the VSJ when implemented into a warmup protocol as an activation exercise.

**References**

Babu, S. K., & Paul, A. (2018). *effectiveness of Nordic hamstring exercise in improving hamstring muscle flexibility, strength and endurance among young adults*. International Journal of Health Sciences and Research. Retrieved October 28, 2022, from https://www.semanticscholar.org/paper/Effectiveness-of-Nordic-Hamstring-Exercise-in-and-Babu-Paul/6ef958ab70232e7586be29e44fe347e947d064f2

Baker, D. (1996). *Improving vertical jump performance through General, Special, and Specific Strength Training*. The Journal of Strength and Conditioning Research. Retrieved October 28, 2022, from https://journals.lww.com/nsca-jscr/Abstract/1996/05000/Improving_Vertical_Jump_Performance_Through.15.aspx

Blache, Y., & Monteil, K. (2014). *Influence of lumbar spine extension on vertical jump height during maximal squat jumping*. Journal of sports sciences. Retrieved October 28, 2022, from https://pubmed.ncbi.nlm.nih.gov/24102076/

Blache, Y., & Monteil, K. (2015). Effects of spine flexion and erector spinae maximal force on vertical squat jump height: A computational simulation study. *Sports Biomechanics*, *14*(1), 81–94. https://doi.org/10.1080/14763141.2015.1024278

Bobbert, M. (1996). *The role of the hamstrings in human vertical jumping*. IEEE Xplore. Retrieved October 28, 2022, from https://ieeexplore.ieee.org/document/651892

Bobbert, M., & van Zandwijk, J. (1999). *Dynamics of force and muscle stimulation in human vertical... : Medicine & Science in Sports & Exercise*. Institute for Fundamental and Clinical Human Movement Sciences. Retrieved October 28, 2022, from https://journals.lww.com/acsm-msse/Fulltext/1999/02000/Dynamics_of_force_and_muscle_stimulation_in_human.15.aspx

Christensen, B., Bond, C. W., Napoli, R., Lopez, K., Miller, J., & Hackney, K. J. (2020, February 1). *The effect of static stretching, mini-band warm-ups, medicine-ball warm-ups, and a light jogging warm-up on common athletic ability tests*. International journal of exercise science. Retrieved October 28, 2022, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7039492/

Cleather, D. J. (2018, July 20). *An important role of the biarticular hamstrings is to exert internal/external rotation moments on the tibia during vertical jumping*. Journal of Theoretical Biology. Retrieved October 28, 2022, from https://www.sciencedirect.com/science/article/abs/pii/S0022519318303369?via%3Dihub

Ferri-Caruana, A., Mollà-Casanova, S., Baquedano-Moreno, M., & Serra-Añó, P. (2022, April 27). *Electromyographic activity of posterior kinetic chain muscles during hamstring strengthening exercises*. Physical Therapy in Sport. Retrieved October 28, 2022, from https://www.sciencedirect.com/science/article/pii/S1466853X22000591

Gallego-Izquierdo, T., Vidal-Aragón, G., Calderón-Corrales, P., Acuña, Á., Achalandabaso-Ochoa, A., Aibar-Almazán, A., Martínez-Amat, A., & Pecos-Martín, D. (2020, July 27). *Effects of a gluteal muscles specific exercise program on the vertical jump*. International journal of environmental research and public health. Retrieved October 29, 2022, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7432749/

Heffernan, C. (2021, December 3). *Why the nordic curl is older than you think*. Physical Culture Study. Retrieved October 28, 2022, from https://physicalculturestudy.com/2021/12/10/why-the-nordic-curl-is-older-than-you-think/

Holt, B., & Lambourne, K. (2008). *The impact of different warm-up protocols on vertical jump... : The Journal of Strength & Conditioning Research*. LWW. Retrieved October 28, 2022, from https://journals.lww.com/nsca-jscr/Fulltext/2008/01000/The_Impact_of_Different_Warm_Up_Protocols_on.33.aspx

Iga, J., Fruer, C., Deighan, M., Croix, M., & James, D. (2012). *'nordic' hamstrings exercise - engagement characteristics and training responses*. International journal of sports medicine. Retrieved October 28, 2022, from https://pubmed.ncbi.nlm.nih.gov/22895870/

Kozinc, Ž., Šarabon, N., Smajla, D., & Žitnik, J. (2021). *The difference between squat jump and countermovement jump in 770 male and female participants from different sports*. European journal of sport science. Retrieved October 28, 2022, from https://pubmed.ncbi.nlm.nih.gov/34075858/

Markovic, G. (2007, June 1). *Does plyometric training improve vertical jump height? A meta-analytical review*. British Journal of Sports Medicine. Retrieved October 28, 2022, from https://bjsm.bmj.com/content/41/6/349.short

Marušič, J., & Šarabon, N. (2020, June 17). *Comparison of electromyographic activity during Nordic hamstring exercise and exercise in lengthened position*. European journal of translational myology. Retrieved October 28, 2022, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7385688/

Mellor, L. (2020, January 1). *The effect of full range Nordic hamstring curls during pre-activation warm-up sessions on hamstring eccentric strength, neural activation and athletic performance in English Academy Soccer*. University of Huddersfield Repository. Retrieved October 28, 2022, from https://eprints.hud.ac.uk/id/eprint/35433/

Mjolsnes, R., Arnason, A., osthagen, T., Raastad, T., & Bahr, R. (2004). A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. *Scandinavian Journal of Medicine and Science in Sports*, *14*(5), 311–317. https://doi.org/10.1046/j.1600-0838.2003.367.x

Padulo, J., Tiloca, A., Powell, D., Granatelli, G., Bianco, A., & Paoli, A. (2013). EMG amplitude of the biceps femoris during jumping compared to landing movements. *SpringerPlus*, *2*(1). https://doi.org/10.1186/2193-1801-2-520

Phillips, W., Burkett, L., & Ziuraitis, J. (2005). *The best warm-up for the vertical jump in college-age athletic men.* Journal of strength and ... Retrieved October 28, 2022, from https://www.academia.edu/1113682/The_best_warm_up_for_the_vertical_jump_in_college_age_athletic_men?auto=citations&from=cover_page

Siddle, J., Greig, M., Weaver, K., Page, R. M., Harper, D., & Brogden, C. M. (2018). Acute adaptations and subsequent preservation of strength and speed measures following a Nordic hamstring curl intervention: A randomised controlled trial. *Journal of Sports Sciences*, *37*(8), 911–920. https://doi.org/10.1080/02640414.2018.1535786

van den Tillaar, R., Solheim, J. A. B., & Bencke, J. (2017, October). *Comparison of hamstring muscle activation during high-speed running and various hamstring strengthening* *exercises*. International journal of sports physical therapy. Retrieved October 28, 2022, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5685404/

van Dyk, N., Behan, F. P., & Whiteley, R. (2019, November 1). *Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: A systematic review and meta-analysis of 8459 athletes*. British Journal of Sports Medicine. Retrieved October 28, 2022, from https://bjsm.bmj.com/content/53/21/1362.info