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Rafał Jacek Studnicki *, Marcin Taraszkiewicz , Urszula Tomaszewicz , Anna Koelmer

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Effects of Nordic Hamstring Exercise on Knee Joint Muscle Strength in Adolescent Soccer Players: A Pilot Study

Marcin Taraszkiewicz [1,2], Urszula Tomaszewicz [1,2], Anna Koelmer [3], Rafał Studnicki [1,2,*]

[1] Department of Physiotherapy, Medical University of Gdańsk, 7 Dębinki Street, 80-211 Gdańsk, Poland; marcin.t99@gumed.edu.pl (M.T.); urszula.tomaszewicz@gumed.edu.pl (U.T.)
[2] Student Scientific Circle of Orthopedic Manual Therapy, Medical University of Gdansk, 7 Dębinki Street, 80-211 Gdansk, Poland
[3] Centre of Biostatistics and Bioinformatics Analysis, Medical University of Gdańsk, Dębinki 1, 80-211 Gdańsk, Poland; anna.koelmer@gumed.edu.pl
* Correspondence: rafal.studnicki@gumed.edu.pl

Abstract: Introduction: The high interest in sports among young people has contributed to the growing importance of the phenomenon of sports specialization in recent years. It refers to players who train a particular sport for more than 80h per month. This is particularly noticeable in the group of young soccer players, in whom such a high training volume, is an important factor predisposing to the development of injuries. An important risk factor is the common lower limb muscle imbalance in the soccer player population between the extensors and flexors of the knee joint, showing a maximum isometric force ratio as low as 1:2. To compensate for this imbalance, it is important that eccentric exercises have a positive effect by improving the strength of the knee joint flexor muscles, especially the well-studied Nordic hamstring exercise(NHE). However, many studies only evaluate the effect of modified NHE exercise training volume, without isolating the effects of performing a single exercise session. It is worth noting that, there are warm-up protocols that incorporate the aforementioned exercise and enjoy high utility and effectiveness for sports injury prevention. Objective: Given the emerging imbalance in the strength of the knee stabilizing muscles, the aim of the study was to determine whether performing a single NHE intervention would alter the isometric strength of the knee flexor muscles (HAM). Methods: A group of 56 players of a youth soccer team (age range 13-16), were recruited for the pilot study. In doing so, the players constituted a group of healthy, training soccer players at the central junior level. After meeting the inclusion criteria, 32 players were entered into the study. Participants were randomly assigned to a study group (A) and a control group (B). In the study group, the intervention consisted of a single NHE exercise in the form of two series of trunk slumps in a kneeling position, eight repetitions each. The control group performed one series of forward trunk bends, five repetitions each. Participants (group A and B) were tested on the ` platform before the experimental procedure and immediately after the intervention. Maximum isometric strength of the knee joint extensors (QUAD) and knee joint flexors (HAM) were measured. Results: Statistical analysis of the obtained results indicated that the maximum muscle strength of the HAM increased after the performed, single intervention NHE ($p=0.04$) relative to the control group. At the same time, no increase in the strength of the quadriceps muscles of the thigh (extensors of the knee joint) was shown after the intervention, relative to the control group. Conclusions:
The results obtained indicate that a single performance of the NHE exercise has an effect on increasing the maximum isometric strength of the HAM muscles. This increase, although not statistically significant, correlated with no change in quadriceps muscle strength. The work is a pilot study and further research may benefit in maintaining the balance between the two muscle groups, namely HAM and QAD, which contributes to the prevention of joint-muscle injuries. At the same time, the study supports the previously stated thesis that a single performed Nordic Eccentric Exercise is an important element in the prevention of muscle injuries in the lower limb, thus confirming the effectiveness of its use in football warm-ups. Nonetheless, implementation of the exercise into long-term training is necessary to achieve significant effects of muscle balance compensation in the lower limb, as confirmed by numerous training protocols.

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1. Introduction

With the growing interest in physical activity among young people, the phenomenon of sports specialization is increasingly playing a significant role in the field of physiotherapy [17]. This has allowed the introduction of an important aspect of training soccer players, which is prevention from injury, which is based, among other things, on the analysis of risk factors of a specific sport [2]. The results of a study by López-Valenciano et al. indicated that the frequency of lower extremity injuries in soccer players was a significant predictor of subsequent injury, at 6.8 injuries per 1,000 hours of training exposure. These mainly included injuries to the musculoskeletal apparatus representing the most common types of injury, occurring at a rate of 4.6 injuries per 1,000 hours of training and competition [2,10]. As suggested by a study by McCall et al, a major risk factor for the development of knee joint injuries is a muscular imbalance between the hamstrings (HAM) and quadriceps (QUAD) groups [10]. Muscle imbalance between the aforementioned groups often leads to muscle tendon overload, especially of the hamstring group, as repeatedly confirmed by research results [1–8,10,15,16]. In the population of football players, the authors of studies repeatedly point out differences in muscle strength between QAD and HAM, which are characteristic of this group of athletes [5,7]. These manifest themselves in an increased HAM:QUAD ratio, which ranges from 1:4 to 1:2 [5,7] According to studies, this difference appears as young soccer players develop, contributing to an increased rate of injury to the hamstring muscles [7,8]. Players who were implemented with HAM muscle strength training showed similar injury risks as players without muscle strength imbalance (QUAD and HAM) [8]. In contrast, Kellis et al. investigating the QUAD:HAM maximum muscle strength ratio as a risk factor for the development of anterior cruciate ligament injuries and injuries to the hamstring muscle group, reached the opposite conclusion to previous studies, suggesting that this ratio has limited diagnostic value for assessing injury risk [5].

To date, researchers have developed numerous training protocols that increase functional capacity and improve muscle balance in the lower limb [11]. Most of them focus on isolated eccentric or concentric exercises of the hamstring muscle (HAM) group, as in the case of Roald Mjølsnes' training protocol [11]. His 10-week exercise plan showed significant improvements in strength parameters, including a 7% increase in isometric and 11% increase in eccentric isokinetic peak force moment [11]. Collected by van der Horst et al, in 2015 the use of NHE in the regular training of amateur teams showed a significant reduction in the incidence of sciatic and shin muscle injuries [12]. Importantly, the improvements in the aforementioned parameters using the NHE protocol exceeded those observed in the concentric counterpart group, particularly involving the hamstring muscles [12].

Comparing the effects of concentric and eccentric exercises among football players, Kaminski et al. in an elaborated study showed improvements in muscle strength in both groups (19% to 29% increase in maximal isometric strength, respectively), however with a higher effect of increased strength with the eccentric exercise protocol [13]. Teams that included NHE in their preparation plan achieved lower injury rates during the season [14].

So far, it has not been studied whether the use of a single NHE intervention can have an effect on improving muscle strength parameters of the knee flexor group. Previous studies have focused on the effects of using long-term eccentric training in the range of 6 to 10 weeks and its modifications in terms of volume [11]. To determine the maximum generated isometric force for the QUAD and HAM muscle groups, the ForceFrame platform from VALD Performance Group (Australia, Brisbone) was used. This makes it possible to assess muscle strength in functional positions that young athletes use on a daily basis in the game, i.e. assessing the QUAD group in a standing momentum-like position that mirrors the kicking element of the ball, and for the HAM assessment, a forward leaning standing position that mirrors the elements of sprinting. A similar use of the ForceFrame platform was proposed by Kadlec et al. in a study to determine the reliability of these measurements for single-

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and multi-joint muscle strength in Australian female soccer players. The results indicate high precision of the measurements and their reproducibility in a population of soccer players [15].

With these reports from the literature in mind, the authors of the present study attempted to conduct a pilot study to evaluate whether a single application of the NHE has an effect on increasing the isometric strength of the muscles of the hamstring group. The indicated form of single application of the exercise was aimed at testing whether performing NHE as part of a warm-up before training or football competitions has an impact on reducing the risk of muscle injury.

2. Materials and Methods

2.1. Ethics

The study was approved by the Independent Bioethics Committee for Scientific Research at the Medical University of Gdansk (approval dated 0.7.07.2023, Resolution No. NKBBN 392 /2023), in cooperation with the AZS Central Academic Sports Center in Gdansk. The content of the study was explained in detail to the participants with an easy-to-understand description of the study protocol, and written informed consent was obtained from the parent or legal guardian prior to participation in the study. For the reliability of the evaluation of the therapeutic effect, the volunteers were tested twice by the same physiotherapists.

2.2. Participants

Initially, 56 healthy soccer players from the ESCOLA Varsovia soccer academy, which plays at the central level of junior competition (Central Junior League), applied to participate in the study. In the next stage, the enrolled volunteers were qualified for the study on the basis of inclusion criteria: healthy volunteers aged 13-16 along with the consent of a parent/legal guardian, and exclusion criteria: lack of consent from the child or parent/legal guardian, previous resistance training, history of lower limb and lumbar spine surgery, injury to the lower limb in the last 6 months (hip, knee, ankle), pain in the hip, knee or ankle, joint hypermobility in the lower limb, neurological diseases, connective tissue diseases.

After questionnaire verification, 32 participants who met the inclusion criteria were assigned to the main part of the study. Twenty-four participants were excluded from the study due to: lack of written parental consent (n-7), recent muscular injuries to the lower limb (n-5), experiencing pain in the knee joint (n-4), previous history of strength training including regular NHE (8).

(Figure 1). The study was a pilot study.

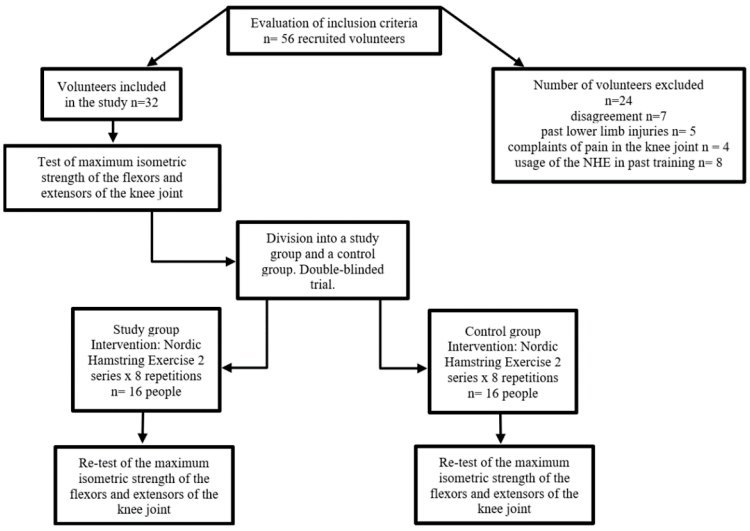

Figure 1. Diagram of the study.

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2.3.Experimental Procedures

A randomized, double-blind, controlled trial was conducted to evaluate the effects of Nordic Hamstring Exercise on hamstrings (HAM) and quadriceps (QUAD) muscle strength. The study was conducted at the "AZS Central Academic Sports Center in Gdansk, Poland," a research laboratory. The first stage was the collection of demographic and anthropometric data of the participants. Then the participants were given a verbal detailed explanation of the test procedure. Three attempts were allowed to read the test without recording the results. Two members of the research team supervised the testing, who ensured that the order of testing was followed and encouraged volunteers verbally during testing. The collected data was automatically uploaded to a digital platform (Vald Performance Brisbane, Australia). In each participant it was assessed:

1. Knee extension- (ExtAF-average extension force obtained from 3 measurements, ExtMF- maximum extension force)-standing position (QUAD), 3 contractions of 5 seconds each, 30-second break using a ForceFrame dynamometer.
2. Knee flexion- (FlexAF average flexion force obtained from 3 measurements, FlexMF maximum flexion force)- standing position (HAM) 3 contractions of 5 seconds each, 30 second break using ForceFrame dynamometer.

After the above analyses, volunteers were randomly assigned to one of two groups: test (group A, n=16) or control (group B, n=16). In group A, volunteers were subjected to an intervention in the form of performing the NHE exercise, while in group B, the same person performed a placebo intervention in the form of forward trunk bends.

2.3.1. Isometric Strength Assessment

Participants (both Group A and B) were tested using the ForceFrame Strength Testing System (Vald Performance Brisbane, Australia). To assess the HAM muscles, the participant was tested according to the manufacturer's suggested procedure. The foot of the test leg was placed in the middle of the dynamometer to record the force using 50 Hz sensors. For the evaluation of the QUAD muscles, the test was conducted according to the manufacturer's guidelines. The forefoot of the lower leg was placed in the middle of the dynamometer to record the force using 50 Hz sensors.

Maximum voluntary contractions (MVC) of each muscle group (HAM and QUAD) were measured for three five-second trials with 30 seconds rest between repetitions. The average of the three tested values (Mean, Peak mm) was recorded as the score in each muscle group for each volunteer. Data with maximum and average total trials were used for analysis [15].

2.4. Description of Intervention

All participants were briefed on the exercise protocol before the study began. Before each exercise group, the study instructor demonstrated how to properly perform the exercise and discussed how to perform it. The necessity of keeping the arms bent at the torso (palm facing forward) to ensure a safe landing on the ground after the performed torso drop was emphasized. Attention was also given to the key element of keeping the hips straight throughout the torso drop movement. Each participant began the NHE in a kneeling position on the mat. Participants were advised to report the sensation of muscle spasms immediately, in order to prevent the occurrence of excessive tension during the exercise. Participants were provided with the opportunity to use three trial repetitions immediately after learning the exercise instructions.

The exercise protocol consisted of performing two series of Nordic torso slumps. In each series, participants performed eight repetitions of the indicated exercise. There was a 60s rest period between series. The way the exercise was performed was supervised by the study instructor.

The placebo intervention protocol in the control group consisted of a single series of 5 repetitions of forward trunk bends, performed from a standing position (leg spread relative to hip width). Each trunk inclination was performed below knee height to a moderate stretching sensation in the back of the thigh. The course of the intervention was supervised by the study instructor.

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2.5. Statistical Analysis

Data were prepared using Microsoft Excel software, and statistical analyses were performed using RStudio version 4.2.3 (R Core Team, 2021). Data were presented using the mean along with a 95% confidence interval.=. Descriptive analysis of demographic characteristics was performed to summarize the data. The Shapiro-Wilk test was used to check the normality of the distribution of each variable. A two-factor ANOVA with repeated measures, both between-group and within-group variance, was conducted to assess the statistical significance of the effect of group (test/control) and measurement (first/second) on the analyzed parameter. An F-test was used for this purpose, followed by a post-hoc test (Student's t-test with repeated measures) to analyze in detail the statistically significant relationships for each pair of measurements. A significance level of α=0.05 was adopted for all tests.

An effect score of 2 was also used - values up to 0.06 indicate a small effect, up to 0.14 is a medium effect, and values greater than 0.14 indicate a large effect.

3. Results

The results obtained from statistical analysis indicate that the maximum muscle strength of the hamstring group (knee flexors) increased after the NHE intervention (p=0.04) relative to the control group. At the same time, no increase in the strength of the quadriceps-thigh muscles was shown after the intervention relative to the control group (Table 1).

Table 1. Descriptive statistics (mean ± standard deviation) of the kinematic variables obtained pre and post intervention.

Testing Time	Study Group[1]	Control Group[1]	Difference between groups[2]
		ExtAF	
Before	301.08 (252.41-349.74)	352.33 (307.39-397.26)	-51.25 (-114.73-12.23), p=0.11
After	315.52 (273.78-357.26)	334.15 (265.59-402.72)	-18.63 (-96.23-58.97), p=0.625
		ExtMF	
Before	362.99 (267.63-458.36)	373.65 (328.33-418.96)	-10.66 (-113.54-92.23), p=0.832
After	338.66 (291.95-385.36)	352.47 (279.92-425.02)	-13.81 (-97.09-69.46), p=0.736
		FlexAF	
Before	196 (170.65-221.35)	233.35 (188.23-278.48)	-37.35 (-87.51-12.81), p=0.137
After	199.03 (177.63-220.43)	195.89 (149.75-242.04)	3.14 (-46.47-52.74), p=0.897
		FlexMF	
Before	196 (170.65-221.35)	252.52 (206.48-298.55)	-56.52 (-107.48--5.55), p=0.0312
After	213.03 (192.4-233.66)	211.66 (164.01-259.32)	1.37 (-49.38-52.12), p=0.956

ExtAF-average upright force obtained from 3 measurements. ExtMF-maximal upright force. FlexAF-average bending force obtained from 3 measurements. FlexMF-maximum bending force.

4. Discussion

The current study was designed to verify whether a single performance of NHE alters the strength of the knee joint flexor muscles. Another aspect was to verify whether the muscle balance of the flexors and extensors of the knee joint is equalized after performing NHE. Given the aforementioned effects, another goal was to see if performing the NHE in the warm-up before training or soccer competitions would effectively reduce the risk of muscle injury.

The results obtained indicate that the maximum isometric muscle strength of the HAM group increased after the exercise intervention. At the same time, the values of maximum muscle strength before and after performing NHE in the QUAD group were not significantly different from each other. This may suggest an equalization of the muscle balance between the flexors and extensors of

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the knee joint. According to current knowledge, an adequate proportion of antagonistic muscle strength has an effect on offsetting the percentage of muscle injuries [5].

To date, scientific studies using NHE have only evaluated the effect of long-term application (usually a period of 4-10 weeks) of NHE exercises on changes in muscle strength within the QAD and HAM muscles in the knee [11]. A large percentage of researchers conducting scientific studies using NHE, rely on a so far proven, exercise protocol, which was prepared by Mjølsnes et al [11]. It consists of a 10-week training plan in which participants perform NHE at a frequency of 1-3 sessions in successive weeks [11]. According to Cuthberth et. al. in a 2020 study to determine the most beneficial NHE training volume in soccer players, training programs lasting in the range of 4-6 weeks show the highest rate of significance for increasing muscle strength of the QUAD and HAM groups [9]. In contrast, our study showed improvements in HAM group muscle strength after just one application of the exercise among the volunteers studied.

Subsequent study authors have modified this protocol by changing the training volume on a weekly basis or within a given training session. However, so far there has been no reported attempt to see what immediate effects a single session using NHE produces [12,13]. The inclusion of NHE in the training program of soccer players is aimed at directly increasing the strength of the HAM muscle group. Indirectly, this activity has the effect of equalizing the difference in generated force between the QUAD and HAM groups of the same limb [19]. As reported by Kong at all. in a 2010 study, a ratio of HAM group muscle strength asymmetry in the left and right limb exceeding 15% has a significant impact on the development of knee joint injury [19]. As Pietraszewski et al. noted in a 2023 study, performing unilateral exercises should be enforced equally significantly to equalize the muscle strength of the left and right HAM group in the lower limb [6].

The results obtained suggest that the implementation of the NHE exercise as part of the warm-up protocol prior to training or soccer competitions, may be an effective component of muscle injury prevention. The reason for this is to increase the muscular strength of the HAM group while maintaining the strength of the QUAD group muscles, thus balancing the muscular balance within the knee joint. Similar findings were made by researchers preparing the FIFA 11+ program, who used NHE as one element of injury prevention among young athletes.

5. Conclusions

The results obtained in the conducted study indicate that a single performance of the Nordic Hamstring Exercise improves the maximum strength of the muscles that flex the knee joint. At the same time, with the constant strength of the muscles that straighten the knee joint, the application of the NHE exercise influences the alignment of the muscle balance between the QUAD and HAM groups. These results indicate that NHE is an important element in the prevention of muscular injuries in the lower limb, and its implementation in long-term training is still recommended to achieve significant effects of alignment of muscle balance in the lower limb. The athletes participating in the study were a homogeneous group in terms of age, physical conditions, mental preparation, or sports discipline. The effect of applying a single performance of NHE among different age groups of soccer players and other sports is worth testing.

In subsequent studies, an additional aspect worth examining is the effect of muscle work in the form of "overcoming isometrics". This is a specific type of isometric muscle contraction that allows more muscle fibers to be recruited for exercise in a short period of time.

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Institutional Review Board Statement: The Independent Bioethics Committee for Scientific Research at the Medical University of Gdansk approved the study (approval dated 0.7.07.2023, Resolution No. NKBBN 392 /2023) and the study was conducted accordingly to the Declaration of Helsinki.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study

Data Availability Statement: Data used in this study is available on a reasonable request of an interested scientist.

Conflicts of Interest: The authors declare no conflicts of interest.

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