HUMAN MOVEMENT (ISSN 1899-1955)
2024; 25(2): 64–85

The Nordbord usefulness in football: a systematic review of the pros and cons

review paper
DOI: https://doi.org/10.5114/hm/189166

DIMITRIOS KOUKOURAS[1], ATHARVA TERE[2], PETROS KOUKOURAS[3], MONÈM JEMNI[4,5,6]

[1] Juventus Academy Nanjing, Nanjing, China
[2] Reliance Foundation Young Champs, Navi Mumbai, India
[3] S.C. Kiyovu Sports, Rwanda (professional football club, tier 1)
[4] Department of Neurology, Carrick Institute, Cape Canaveral, Forida, USA
[5] Faculty of Physical Education, Ningbo University, Ningbo, Zhejiang, China
[6] Centre for Mental Health Research in Association, University of Cambridge, Cambridge, UK

ABSTRACT
Since 2016 and the introduction of Nordbord to the world, a variety of sports and disciplines have used the device to inform everyday decision-making, such as post-match recovery, to assess players' readiness for the next fixture and mitigate the risk of injury. The objective of this paper was to examine the use of Nordbord across all football (soccer) levels and present practical recommendations concerning its application and potential limitations as a tool for measuring eccentric strength of the knee flexors (ESKF) incorporating the critical role of hamstring eccentric strength (HES) in injury prevention and performance enhancement. Twenty-nine studies were identified and met the inclusion criteria. The review shows that although Nordbord has potential as a practical and cost-effective method of measuring HES, the findings on the validity and reliability are conflicting. Furthermore, the study highlights several topics where the Nordbord could be recommended to stakeholders, as a tool to assess post-match recovery, prevention of hamstring injuries, and rehabilitation, as well as used as a performance indicator for balance, sprint, and change of direction performance. However, the review showed that ESKFs could be affected by fatigue and training volume, therefore, there is a need for normative values for different ages, genders, levels, and positions. Furthermore, the need for standardized methods and normalized data gathering, are argued as pivotal points to establish the Nordbord as a valuable alternative to the isokinetic dynamometer.
Key words: soccer, injury prevention, return to play, recovery, performance, hamstring eccentric strength

Introduction

The utilization of eccentric strength of the knee flexors (ESKF) as a performance measurement has been suggested concerning several aspects of football within the past decade, not only within the injury prevention and rehabilitation context but also in recovery and sprint performance. The hamstring muscle group is one of the most commonly injured muscles in professional football, accounting for 12% of all injuries and representing 37% of all muscular injuries sustained [1, 2]. These injuries not only have financial implications but also impact player performance, particularly during high-speed running [3]. Hamstring injuries (HI) are a concern at the elite youth level and can hinder player development [4]. Research has established a correlation between reduced eccentric strength, interlimb imbalances, previous HIs, and an increased risk of injury, along with significant strength reductions post-injury [5–8].

Several recent research studies have proposed HI rehabilitation protocols based on eccentric hamstring strength [9–15]. Improving hamstring eccentric strength (HES) through various exercise modalities has shown positive effects [16] on sprinting performance in football players [17, 18], and the Nordic hamstring exercise (NHE) has been indicated as an important factor in improving HES [19] as well as sprint performance [20–22]. In addition, timing ESKF strengthening post-training is crucial in reducing the negative effects of

Correspondence address: Dimitrios Koukouras, Juventus Academy Nanjing, Youth Olympic Sports Park, 2 Huanao Rd., Jianbei New District, Nanjing, China, e-mail: dimi.koukouras.86@gmail.com

Received: December 23, 2023
Accepted for publication: May 21, 2024

Citation: Koukouras D, Tere A, Koukouras P, Jemni M. The Nordbord usefulness in football: a systematic review of the pros and cons. Hum Mov. 2024;25(2):64–85; https://doi.org/10.5114/hm/189166.

fatigue [23]. In the past decades, muscle imbalances and HES are commonly measured using the isokinetic dynamometer [16] as a reliable tool. Furthermore, various handheld dynamometers have been used, showing moderate reliability when the subject exhibits high muscle strength or when the examiner is not sufficiently experienced, but high reliability in clinical settings [24–30].

In January 2016, the Nordbord Hamstring Testing System was introduced to the public, after almost a decade of development and research [31, 32]. This innovative device, manufactured by VALD Performance, has gained widespread use in sports rehabilitation and performance enhancement programs across various sports and clinical settings. According to the manufacturer [33], the Nordbord offers a quick and versatile way to assess hamstring strength and imbalance through multiple positions and exercises, aiding professionals in understanding HIs, rehabilitation, injury prevention, and performance optimization. Although the "conflict of interest section" at the bottom of this article mentions no conflicts, the authors wanted to make it clear that none of them have any relation of any kind or any direct or indirect financial benefits with the company and/or its retailers/distributors. Our interest is purely driven by the science and the application of this device in football. We hope to provide unbiased, scientifically based pros and cons that could be useful for scientists and field users.

The Nordbord consists of a horizontal board with an integrated force platform and a strapping system to secure the user's feet, effectively replicating the NHE at different angles and providing valuable data on both eccentric and isometric strength indicators for the hamstrings (Figure 1). Live data from the Nordbord can be transmitted to connected devices, displaying the force produced in Newtons for each limb, and this data has the potential to amass a wealth of information from different sports and countries and develop normative data for each sport [34].

To appreciate the rapid adoption of the Nordbord in sports, it is essential to examine the conventional method of testing ESKF. Historically, isokinetic dynamometry has been the gold standard for ESKF measurements [35, 36]. Despite its ability to offer a wide range of data and precise results, isokinetic dynamometry has limitations that hinder its widespread use. These limitations include space requirements, as it can only be used in specialized indoor lab settings by trained professionals [37]. Furthermore, the high cost of isokinetic dynamometers, ranging from £35,000 to £90,000 ($45,000 to $115,000) depending on the brand, restricts its accessibility to only affluent sports clubs and teams. Several researchers have recognized the need for a more cost-effective and portable alternative for ESKF assessment [38, 39].

The Nordbord not only delivers faster results through an automated process, with a player's test-taking approximately 30 s, but it is also highly portable, enabling testing in various settings, including the pitch and dressing room, without requiring extensive space. Additionally, the cost of the Nordbord, including software and support, does not exceed £3,800 or $5,000 per year [40]. Research has demonstrated that eccentric hamstring strength assessment is a reliable alternative to isokinetic measurements [38, 39], offering a cost-effective means to assess inter-limb asymmetries while considering the hip position and participants'

Figure 1. Photo of a Nordbord device and a demonstration of the NHE

body mass (BM) [38]. In certain sports, such as skiing, an eccentric hamstring strength assessment may be more suitable than isokinetic strength measurements because the biomechanics of the sport involve more bilateral eccentric contractions than unilateral isometric contractions [41]. There are, however, several other handheld dynamometers available on the market with more affordable prices.

While the Nordbord has found widespread use in sports, this review aims to focus specifically on its application in football and identify potential research gaps. Football is one of the most popular sports in the world and attracts millions of athletes and a large market pool that encompasses not only athletes but also experts from different backgrounds. Therefore, the objective of this paper is to examine the use of Nordbord across all football (soccer) levels and present practical recommendations concerning its application and potential limitations as a tool for measuring ESKF, incorporating the critical role of HES in injury prevention, recovery, and performance enhancement.

Material and methods

Searches were conducted using the PubMed and Sports Discus databases. Given that Nordbord was introduced in 2016, a starting date for our search was not specified. The search was conducted up to the 28th of February, 2023. The search term "Nordbord" was applied to all fields.

The search applied the PRISMA protocol. A total of 151 studies were identified, with 20 in PubMed and 131 in Sports Discus. Studies were initially screened based on their titles and language, including only those in English and Spanish. Studies that mentioned sports other than football/soccer in their titles were excluded, while those that did not specify the research group remained included at this stage. This step reduced the number of studies to 65.

Next, the abstracts of the remaining papers were reviewed. This led to the exclusion of an additional 19 studies, either because they did not meet our inclusion criteria (the use of Nordbord and football) or because they were duplicates. The full text of the remaining 46 research papers was then reviewed.

Inclusion criteria focused on studies conducted on football players, regardless of the level or gender, that utilized the Nordbord for the measurement of HES. Studies that described the device without mentioning its name but referenced other research where the Nordbord was used were also included.

Following this rigorous selection process, a total of 29 articles were included in this review. A visual representation of the entire process is presented in Figure 2.

Results

Reviewing the 29 articles has provided a thorough insight into the challenges and opportunities that the Nordbord equipment offers (Table 1, see before references). These are disseminated in the following sections, where each displays the findings, followed by a short discussion.

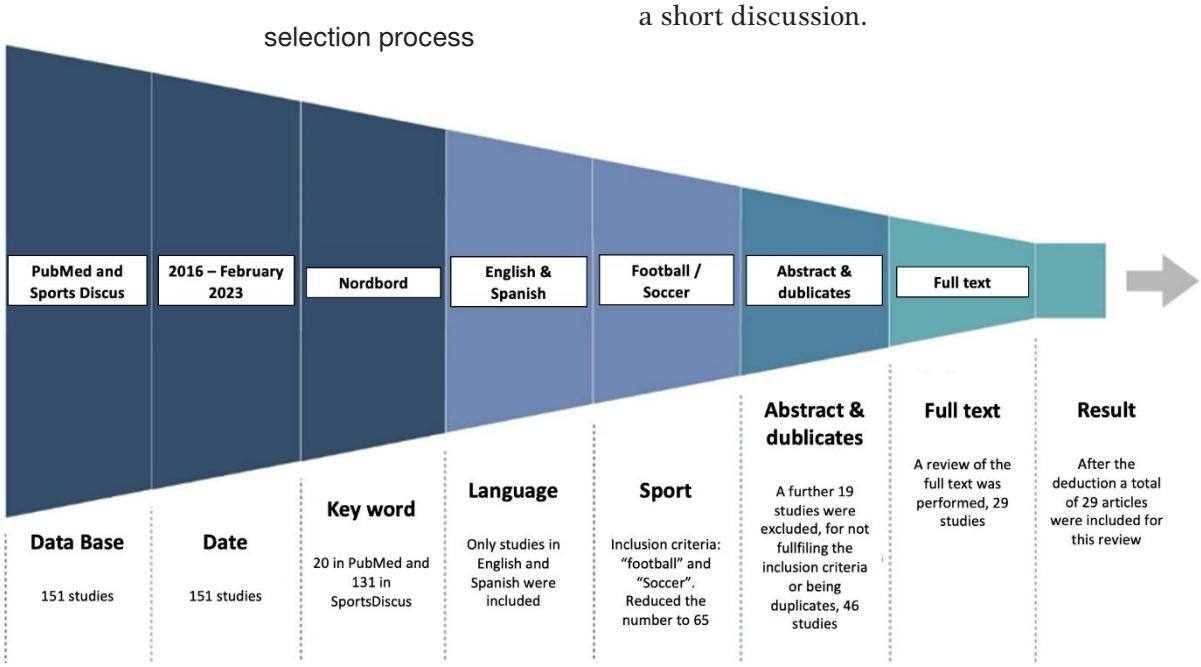

Figure 2. PRISMA Funnel showing the selection process

Issues related to standardization, normalization, and reliability

Buchheit et al. [42] reported a large correlation between eccentric knee-flexor strength, measured using the Nordbord during NHEs, and BM (r = 0.55, 90% confidence limits: 0.42;0.64). In their study, they found that heavier and older athletes outperformed lighter athletes. To address variations in BM, the authors recommended using a regression equation (eccentric strength in N = 4 × BM in kg + 26.1) to estimate expected strength values based on individual BM (N/kg). This approach allowed for a more accurate comparison of actual test scores using the Nordbord among players with differing body masses. Although it could sound logical to use mathematical regression analysis for further prediction, we are not aware if the formula has been validated. In addition, to their findings, Buchheit et al [42] observed that professional soccer players displayed 20% greater relative strength than the expected values for their BM compared to youth players.

In a study conducted by Wik et al. [43] on professional soccer players in Qatar, they explored physical characteristics and positional differences. Goalkeepers were found to have the greatest BM compared to other positions (p < 0.05) and exhibited greater absolute strength compared to strikers and midfielders. However, when comparing eccentric hamstring strength measured using the Nordbord to the expected results based on BM, defenders reported significantly higher values (p < 0.05, effect size d = 0.80) than goalkeepers. This suggests that defenders demonstrate remarkable eccentric hamstring strength in relation to their BM.

Soós et al. [44] conducted a study on Hungarian youth male soccer players and reported that goalkeepers displayed significantly higher scores for dominant (p = 0.01) and non-dominant (p = 0.04) legs on the Nordbord compared to other outfield players, especially midfielders. There was no difference between age groups for HES, which contradicts Buchheit et al. [42]. Notably, this study did not standardize the results based on individual BM, and the values provided are absolute scores.

Sherwood et al. [45] observed significant age-related effects on HES among elite youth soccer players. They found that older age groups, specifically U18 and U23, exhibited significantly higher average HESs than the younger U16 group. However, no significant differences were observed between the U18 and U23 players. These age-related differences in HES were attributed to the influence of structured strength and conditioning programs commonly found in elite-level academies, as well as natural growth and maturation. The authors concluded that the lack of difference between U18 and U23 groups was due to a shift in training focus from greater strength volume to more technical and tactical-oriented training.

In a review by Claudino et al. [46] covering four new technologies for evaluating ESKF, the Nordbord device emerged as the most commonly used instrument for measuring HES. Its popularity stems from its cost-effectiveness compared to isokinetic dynamometers and its technical superiority compared to handheld dynamometers. They found that the bilateral assessment of the NHE using Nordbord demonstrated high to moderate test-retest reliability (ICC = 0.83–0.90, SEM = 6–9%), while lower reliability was observed during unilateral testing (ICC = 0.56–0.73 and SEM = 10–11%). Reliable results for between-limb imbalances were achieved when peak forces were averaged over six trials (ICC = 0.85; 95% CI 0.71–0.93; SEM = 5%, 95% CI 4–6%). Importantly, Claudino et al. [46] highlighted the relatively poor correlation between forces measured by the Nordbord and peak isokinetic hamstring eccentric torque from the gold standard isokinetic dynamometer (r = 0.35; r^2 = 12%). They emphasized the need for standardized methods to assess ESKF on the Nordbord, including averaging results from six trials and normalizing for BM.

In contrast, Ogborn et al. [47] reported highly significant and moderate to high correlations between eccentric hamstring torque measured on the Nordbord and isometric torque measured on an isokinetic dynamometer (r = 0.61–0.86). These correlations varied slightly with different body and foot positions. Additionally, peak eccentric hamstring force measured on the Nordbord demonstrated high test-retest reliability, with ICC values of 0.993 (95% CI 0.983–0.997) for the left leg and 0.992 (95% CI 0.979–0.997) for the right leg.

Bishop et al. [48] monitored 14 professional footballers weekly for eccentric strength over six weeks. They reported moderate reliability between test sessions, with ICC values ranging from 0.54 to 0.73. Absolute reliability remained under the 10% threshold, with only a 0.06% increase between sessions 1 and 2 before dropping below 10% for subsequent sessions. The authors concluded that two familiarization sessions were necessary to achieve reliable peak force measurements using the Nordbord for the NHE.

The study by Rhodes et al. [49] aimed to establish the reliability of quantifying HES in elite youth footballers using both the Nordbord and an isokinetic dynamometer. Their findings revealed remarkable differences between the two devices, with the Nordbord

Table 2. Data of statistically significant correlations found in the study of Rhodes et al. [49]

Measurement	*r* value*	*p*-value**	CI value***
The peak torque on the left (at 60° · s^{-1}) and Nordbord break angle	–0.555	0.026	–0.790 to –0.260
Nordbord break angle and average torque on the left (at 60° · s^{-1})	–0.551	0.027	–0.808 to –0.242
Nordbord break angle and peak torque on the left (at 180°·s-1)	–0.593	0.016	–0.817 to –0.286
Average torque on the left (at 180° · s^{-1}) and Nordbord break angle	–0.616	0.011	–0.833 to –0.300
Nordbord break angle and angle of peak torque for left (at 60° · s^{-1})	0.504	0.047	0.018–0.867
Nordbord break angle and angle of peak torque for right (at 60° · s^{-1})	0.546	0.029	0.095–0.828

* coefficient of correlation (*r*), ** denotes significance level of 0.05, *** confidence Intervals at 95%

displaying greater variance in coefficient of correlation measurements compared to the isokinetic dynamometer.

Specifically, out of a plethora of data measurements gathered, greater variance in metrics was observed for the right limb concerning peak force and peak torque. In contrast, the difference between the left and right limbs was smaller for average force and average torque. Noteworthy, the study does not specify whether the differences observed between right and left limbs were due to dominance/preference. Nevertheless, statistically significant correlations were identified between the two devices for several strength measures, as seen in Table 2.

Importantly, statistically significant correlation coefficients were reported for all metrics on both the isokinetic dynamometer and Nordbord ($p < 0.01$). However, there were no significant correlations between the two devices for any other strength measurements, indicating some discrepancies in the assessment of HES.

These findings highlight the importance of considering the specific metrics and measures used when comparing Nordbord and isokinetic dynamometer results. While some metrics exhibited statistically significant correlations, others did not, highlighting the potential variations in outcomes when using these devices.

Fernandes et al. [50] investigated the reliability of the Nordbord in male youth footballers aged 10–16 years, considering maturation profiles (pre and post-PHV). They reported coefficients of variation (CVs) across age groups for various measures of HES using the Nordbord, including left (5.6–7.4%), right (5.9–8.7%), bilateral (6.1–7.4%), and relative peak force (6.3–6.4%). These CVs were generally favorable; however, none of the typical errors (TEs) were able to detect the smallest worthwhile change (SWC). Additionally, the peak force imbalance between the left and right limbs demonstrated poor agreement between trials (CV = 33.1–38.3%). The reliability of HES measurements for pre-PHV players was generally better than that of post-PHV players, as indicated by lower CVs for the left (5.7 vs. 6.9%), right (4.8 vs. 8.5%), bilateral (4.9 vs. 7.3%), relative peak force (5.0 vs. 7.2%), and imbalance (35.3 vs. 36.1%).

Read et al. [51] examined 203 professional footballers in Qatar, assessing HES using the Nordbord and other strength-related variables for quadriceps and hip muscles. The study aimed to establish a threshold for limb asymmetry, but due to variations in testing procedures between the Nordbord and the isokinetic dynamometer, the authors recommended that testing should be task-specific. They reported that athletes categorized as having extremely high asymmetry (a difference of > 9% on the Nordbord between limbs, with the principal component being quadriceps and hamstring isokinetic strength asymmetry) exhibited reductions in unilateral jump height. Notably, there were no significant positional differences in HES on the Nordbord, which contradicted the findings of a previous study by Wik et al. [43].

These studies stress the importance of considering factors such as maturation profiles and task-specific testing when assessing HES using the Nordbord. The findings also highlight the relevance of limb asymmetry thresholds and the potential impact of these factors on athletes' performance in related activities like jump height and on-field positions.

Other studies emphasized the value of the NHE as a reliable and practical tool for assessing hamstring strength and monitoring changes in inter-limb symmetry, particularly in the context of female elite football players. For instance, the study conducted by Cuthbert et al. [52] provides valuable insights into the reliability and suitability of various tests, including the NHE and kneeling 90° knee flexion (kneeling ISO), for assessing hamstring strength and inter-limb asymmetry in elite female football players. Here, we present a concise summary of their findings.

The authors reported good to excellent between-session reliability for the NHE on the Nordbord, with

intraclass correlation coefficients (ICC) exceeding 0.901 and a lower-bound 95% CI above 0.790. When testing kneeling 90° knee flexion on the Nordbord, they found fair to excellent reliability for the left limb, with ICC values ranging from 0.798 to 0.909 and a lower-bound 95% CI from 0.530 to 0.788.

In terms of inter-limb asymmetry, they observed that the magnitude of asymmetry for the kneeling ISO was –2.76% to +13.94%, while for the NHE, it ranged from 3.94% to 7.41% between sessions. The direction of asymmetry between sessions demonstrated kappa coefficient values that indicated slight to moderate agreement (k = 0.03–0.47) for isometric assessments and substantial agreement (k = 0.62) for the NHE.

Based on their findings, Cuthbert et al. [52] concluded that the NHE on the Nordbord was the most reliable test both within and between sessions. It also demonstrated substantial agreement in identifying inter-limb asymmetry between sessions when used as a bilateral test. This suggests that the NHE on the Nordbord is the most appropriate method for assessing hamstring strength and inter-limb asymmetry over time in elite female football players.

The results of the above-reviewed studies present a conflicting landscape when it comes to comparing the reliability of the Nordbord with the gold standard, the isokinetic dynamometer. Ogborn et al. [47] conducted a comprehensive analysis of various methods for testing knee flexor muscle strength and reported a high degree of correlation between Nordbord measurements and isometric knee flexion torque as measured via the Biodex Dynamometer (r = 0.61–0.86). They also found high test-retest reliability for Nordbord measurements, with values of 0.993 (95% CI 0.983–0.997, n = 19), and established a Minimal Detectable Change with 95% CI of 26.88 N and 28.76 N for the left and right limbs, respectively. Similarly to Rhodes et al. [49], the author does not specify the dominant limb of the participants. However, there are only a couple of Newtons within these 95% CI to detect a significant implication. These findings are in line with several other authors [38, 39, 53] who have also found Nordbord to be a reliable alternative for measuring HES.

However, the literature also includes studies suggesting contradictory results. Authors have indicated that Nordbord may have poor correlation with the isokinetic dynamometer [46, 54], greater variance in the coefficients of correlation measurements [49], and even a tendency to overestimate HES [55].

This divergence in findings raises uncertainty about the extent to which Nordbord can offer a reliable and cost-effective alternative to the expensive gold standard of the isokinetic dynamometer. As suggested by Claudino et al. [46], there is a pressing need for standardized methods for assessing the ESKF on the Nordbord. Additionally, a regression equation, such as the one proposed by Buchheit et al. [42], is required to be validated and tailored specifically for football players. Furthermore, the literature reveals a gap in our understanding of the effects of age, position, gender, and the level of participation for footballers when it comes to Nordbord measurements. These factors need to be considered to establish normalized data that can assist practitioners in various footballing contexts and levels in assessing the HES of their players.

In short, while Nordbord shows promise as a practical and cost-effective tool for assessing HES, the conflicting findings in the literature and the identified gaps in research suggest the need for further investigation, standardization, and refinement to fully establish its reliability and utility in the context of football. This will be essential to ensure its effectiveness as a valuable alternative to the isokinetic dynamometer.

The effects of training volume and protocol specificity

Some studies suggest that increasing training volume may not necessarily lead to greater improvements in HES. The findings of this review also reveal the importance of the specificity of training protocols and the need for monitoring and assessing different aspects of strength and performance in footballers. For example, Lacome et al. [56] conducted a study comparing the effects of low and high volumes of NHE and stiff-legged deadlifts in elite U19 French footballers. After a 6-week training phase, both the low-volume and high-volume groups exhibited moderate increases in HES, along with small gains in biceps femoris and semimembranosus fascicle length. Notably, there were no significant differences or further improvements between the two groups during the subsequent 6-week phase, suggesting a potential ceiling effect. As a result, the authors recommended the use of low-volume, high-intensity eccentric exercises as an effective part of injury prevention protocols, as they were just as effective as high-volume protocols.

Amundsen et al. [54] conducted a randomized trial involving female soccer players from a Norwegian Division two football team. This study aimed to determine the effects of high-volume and low-volume Nordics exercise protocols on HES, jump height, and sprinting

performance. After 8 weeks of training, both the high-volume and low-volume groups showed significant improvements in maximal eccentric force on the Nordbord, regardless of the added weight. However, there was no significant difference between the groups for maximal eccentric force. The study also found poor correlations between Nordbord assessments and isokinetic dynamometer measurements, as well as limited changes in sprinting and jump performance. These results indicate that the training volume did not significantly impact HES in this context.

In addition to the specificity of exercise protocols used in training programs that can influence the outcomes, other findings suggest that NHE interventions may have a positive impact on certain aspects of sprinting and change of direction (COD) performance, particularly in amateur football players. However, the relationship between HES and sprinting ability is complex and may not be a significant predictor of sprint performance.

In a 10-week intervention with amateur football players, Ishoi and their team [20] found that participants who underwent NHE showed improvements in their sprinting performance. Although the group differences in total sprint times were not statistically significant, they favored the intervention group. Significantly, the intervention group exhibited improvements in the fastest sprint time, with a very likely medium effect size, and also in the last 10 m sprint time. The improvements in total sprint times, fastest 10 m sprint time, and last 10 m sprint time ranged from 1.8% to 3.2%. These findings suggest that NHE interventions may positively impact sprinting performance among amateur football players.

However, in a study involving youth soccer players, Jones et al. [18], examined the relationship between body weight-scaled HES measurements using the Nordbord and COD performance. They found that body weight-scaled HES was significantly related to COD performance, specifically on a 505-agility test. However, when predicting sprinting ability at various distances (5, 10, and 20 m), HES did not emerge as a significant predictor. Additionally, the study found that imbalances in HES had minimal effects on both sprinting and COD performance. These results indicate that HES may play a more prominent role in COD performance than in sprinting ability.

Adding to the above, Harøy et al. [55], compared two training programs: one following the standard FIFA 11+ program with NHE and the other replacing NHE with the Copenhagen Adduction (CA) exercise. They found no significant differences in HES between the two programs. However, the group following the standard FIFA + program showed a significant within-group increase in HES. Neither group exhibited significant improvements in sprint times at various distances (5, 10, 15, and 20 m). The study also highlighted the potential overestimation of HES measured on the Nordbord compared to the isokinetic dynamometer, in line with previous research.

Similar to the different findings reported in sprinting and agility, a few studies provided insights into the effects of various NHE interventions on hamstring strength among football players. While some studies reported no significant changes [22], others demonstrated improvements in hamstring strength [20, 54], highlighting, yet again, the need for a better understanding of the specific protocols, participant characteristics, and intervention durations influencing the outcomes.

In a study involving 20 professional football players over 24 weeks with biweekly interventions, Quiceno et al. [57] examined the effects of a hamstring-specific training protocol. The study reported no significant changes in hamstring strength pre- and post-intervention. However, it's essential to note that the participants' scores were not standardized according to their body weight. Further details about the intervention are necessary to make meaningful comparisons with other studies.

However, Quiceno et al. [58] observed the effects of an 8-week intervention performed at a biweekly frequency in female Colombian football players. The intervention plan included NHEs with incremental volume and other exercises, such as Kbox squats with progressive overload. The study reported a significant difference between pre- and post-intervention, indicating an improvement in hamstring strength.

Similarly, Drury et al. [59] investigated the effects of a 6-week NHE program among youth male soccer players. The participants were divided into pre-PHV and mid/post-PHV groups and further categorized into control and experimental groups (1–2 sessions of NHE per week). Within-group analyses showed an increase in relative peak force in both experimental groups, with a greater effect size observed in the pre-PHV group compared to the mid/post-PHV group. Between-group analyses revealed moderate increases in hamstring strength in both maturity groups, with the pre-PHV group showing a larger effect size.

The studies presented in this section highlight the intricate relationship between ESKF, sprint performance, and the role of NHEs in enhancing hamstring

strength. Notably, ESKF is associated with improved sprint performance, emphasizing the significance of hamstring strength in athletic endeavors [60]. Several studies, including Ishøi et al. [20], Siddle et al. [21], and Bautista et al. [22], have proposed NHE as a crucial element for enhancing both hamstring strength and sprint performance.

Additionally, Opar et al. [61] discovered that previous HIs had a negative impact on ESKF improvements during the pre-season. Players with a history of injuries experienced smaller gains in ESKF, which might be a risk factor for potential future injuries. Furthermore, sprint performance tends to decline during the off-season, independent of previous HIs, age, or the duration of the break [5]. This suggests that eccentric strengthening of the hamstring during the pre-season is vital for improving sprint performance and reducing the risk of HIs, underscoring the importance of tools like the Nordbord for assessment and monitoring.

From a physiological perspective, longer fascicle lengths of the muscles are associated with better sprint performance [62]. While Mendiguchia et al. [63] argued that NHEs did not significantly impact biceps femoris long head fascicle length (BFlh FL) or sprint performance, and that sprint training was more effective. Behan et al. [64] and Lacome et al. [56] reported positive outcomes from NHE interventions, including increased HES and BFlh FL. Behan suggested that consistent low-volume NHEs may not yield significant improvements, while Lacome did not make this distinction but reported no increase in the second stage of their study. The differences in results may be attributed to variations in intervention protocols, particularly the volume of NHE performed.

Lastly, it's crucial to note that both HES and BFlh FL can be enhanced through acceleration or maximum speed training, serving as a method for HI prevention [65]. Given the critical role of ESKF in sprint performance, stakeholders can utilize tools like the Nordbord to monitor changes in hamstring strength throughout pre-season and during the season, helping to optimize performance and reduce the risk of injuries.

Issues related to the effect of fatigue on ESKF

This section summarizes findings that provide valuable insights into the effects of fatigue and physical activity on ESKF, emphasizing the importance of considering variables such as absolute and relative strength, inter-limb differences, and physical demands in sports and training programs. The following studies shed some light on the complex relationship between hamstring strength, sprint performance, and stability, providing more understanding of the multifaceted nature of athletic performance and injury prevention in soccer players.

In a study conducted by Brogden et al. [66], the effects of fatigue on ESKF were investigated in a group of male academy soccer players using the Nordbord device. The results showed significant differences in absolute ESKF before and after the Yo-Yo Intermittent Recovery Level 1 (YYIR Level 1) test. Both dominant and non-dominant limbs displayed increased ESKF values post-exercise compared to pre-exercise. Additionally, bilateral differences were observed, with the dominant limb ESKF being significantly higher than the non-dominant limb ESKF post-exercise. The study also revealed differences in ESKF relative to BM, both pre- and post-exercise, between the dominant and non-dominant limbs. Importantly, the authors noted that the Nordbord device was sensitive enough to detect these differences in absolute, relative strength, and inter-limb dominance for ESKF. Moreover, no significant correlations were found between ESKF measurements and the distance covered during the YYIR Level 1 test, suggesting that ESKF changes were not influenced by aerobic fitness.

In another study by Madison et al. [67], the effects of different small-sided games (SSGs) on hamstring isometric torque of the preferred kicking side were examined. Two SSG formats, one with a smaller playing area (3 v 3 in 300 m^2) and the other with a larger area (4 v 4 in 1000 m^2), were compared. The results indicated that the larger SSGs led to significantly greater physical demands, including increased total distance covered, distance covered in different speed zones, max speed, accelerations, decelerations, metabolic power, and heart rate. Importantly, the study revealed that SSGs with a larger relative area resulted in greater reductions in peak and mean isometric forces of the hamstring at a 90-degree knee angle. Post hoc tests confirmed significant differences in the peak and mean force reductions between the small and large SSG conditions. Additionally, the number of accelerations in both SSGs was positively correlated with the change in force at a 90-degree knee angle, highlighting the relationship between acceleration and hamstring force reduction during these activities.

Shah et al. [68] conducted a study to investigate the effects of weekly sprint distance and maximal velocity exposure on HES in professional soccer players. They observed an inverse relationship between total weekly sprint distances and the percentage change in HES, with a very small correlation. Similarly, they found an

inverse relationship between total weekly efforts at maximal sprint speed above 90% and the percentage change in HES, albeit with a very small correlation. The mean percentage change in HES was influenced by weekly efforts at maximal sprint speeds above 90%, showing significant differences between specific sprint effort ranges. They also reported variations in HES among different player positions, with attackers having the highest HES, followed by defenders and midfielders. However, they did not provide a direct comparison of HES between positions, making it challenging to interpret the significance of these findings.

On the other hand, Brünn et al. [69] found no significant correlation between HES and a higher sprinting speed on either the right or left side. Instead, they identified correlations between HES and weight and age, which align with findings from other studies in this area.

In contrast, Rhodes et al. [70] reported significant correlations between various functional hamstring strength metrics measured with the Nordbord and posteromedial and posterolateral stability, indicating the relationship between HES and aspects of stability. These findings suggest that hamstring strength is associated with stability in specific directions, which has implications for injury prevention and athletic performance. However, no significant correlations were observed between HES metrics and anterior stability.

The studies discussed in this section highlight the impact of fatigue on ESKF and knee stability in soccer players. It is evident that a football match or intense soccer-specific activities can lead to a reduction in ESKF and knee stability, which may persist for several days. This reduction in strength and stability could potentially increase the risk of HIs and other lower limb issues in players.

Draganidis et al. [71] emphasized that the total eccentric actions during a match, combined with the player's physical condition, play a crucial role in determining the loss of strength, which can last for up to 60 hours post-match. Matthews et al. [72] showed that a conditioning program focusing on muscular strength or endurance could mitigate the loss of eccentric hamstring strength during and after soccer activities. Kakavas and Kekelekis [73] and Salter et al. [74] presented mixed results, with Kakavas reporting a significant decrease in ESKF after matches and Salter finding no substantial changes following simulated soccer play.

The discrepancies in the findings might be attributed to variations in the test protocols, such as the use of a friendly match, a simulated soccer match, or fatigue-inducing exercises. The choice of test may influence the level and duration of strength reduction observed. The importance of utilizing tests that accurately replicate the eccentric strength demands of a real football match is crucial for obtaining reliable data.

Greig [75] and Dewig et al. [76] provided insights into the relationship between fatigue and knee stability. Greig found that fatigue led to a significant reduction in ESKF and an increase in knee varus at touchdown. Dewig associated hamstring strength with a decrease in various moments during single-leg landings, indicating the importance of strong hamstrings in maintaining knee stability under fatigue.

All in all, the use of tools like the Nordbord can assist performance specialists in evaluating a player's fatigue level and monitoring recovery following matches or intense training sessions. This information can be invaluable for coaches and medical staff in making informed decisions about player readiness and injury prevention strategies. However, more research and data are needed to better understand the effects of fatigue on HES during different post-match and post-training time points, such as match day +1, +2, and +3, to provide a comprehensive picture of a player's recovery dynamics.

The Nordbord as a tool for injury prevention, return to play, and performance monitoring in football

The literature search suggests that previous lower extremity (LE) injuries or non-contact lower limb injuries (NCLLI) may not have a substantial impact on hamstring strength or imbalance [60, 61]. Factors such as body weight and baseline measurements appear to play a more significant role in strength differences among players [77]. However, imbalances in ESKF may be associated with an increased risk of non-contact ACL injuries [78]. The Nordics exercise has been demonstrated as a feasible and well-accepted tool for assessing hamstring strength in soccer players [39, 50].

The effect of previous LE injuries on hamstring strength imbalance (HSI) in soccer players has been a topic of investigation in the literature. Isik et al. [77] conducted a study with young soccer players aged 14 to 19 and found no significant effect of previous LE injuries on HSI. This suggests that prior LE injuries did not have a discernible impact on the imbalance of hamstring strength. It is noteworthy that body weight had a significant effect on HSI, which aligns with previous research, indicating the influence of body weight on this measure.

Similarly, Jones et al. [60] explored the impact of NCLLI on hip, groin, and knee flexor strength development in male academy footballers. They reported that players who sustained an NCLLI had statistically stronger absolute strength for adduction, abduction, and ESKF when compared to their uninjured counterparts. However, when the data was controlled for baseline measures and scaled for body weight, these differences were not significant. This suggests that the differences in strength were likely influenced by body weight and baseline measurements rather than the injury itself. The study also highlighted the potential for strength fluctuations during the season, with stronger players at the beginning of the season losing strength while players with less strength initially gained strength over time.

Collings et al. [78] investigated the relationship between various factors, including isometric hip abductor and adductor strength, ESKF, countermovement jump (CMJ) kinetics, and previous ACL injury history, in the context of non-contact ACL injury prediction. The study found no significant relationship between directional leg asymmetry in strength, ESKF, or CMJ kinetics and the likelihood of sustaining an ACL injury. However, non-directional between-leg asymmetry for ESKF had a significant odds ratio, suggesting that imbalances in ESKF may be associated with an increased risk of non-contact ACL injuries.

Haller et al. [79] focused on the feasibility and acceptance of a series of tests and questionnaires to evaluate the training load in soccer players. The NHE was included as a part of the strength and conditioning session before games. The study found that the best performance in Nordics most often occurred on the first attempt. Additionally, the testing procedures, including the NHE, were generally well-accepted by the players, with only a small amount of missing data attributed to injury or discomfort during the test.

The utilization of ESKF as a performance measurement in football has gained significant attention, particularly in the context of injury prevention, rehabilitation, recovery, and sprint performance. Research suggests that strength deficits, inter-limb imbalances, and previous HIs are predictive risk factors for future injuries in football [8, 80]. It has been proposed that players with ESKF below a certain threshold, such as 2.4 Nm/kg [80], may be at an increased risk of acute HIs, with age potentially exacerbating this risk [7, 81]. The Nordbord, as a tool for assessing ESKF, can be instrumental in monitoring and mitigating this risk.

Numerous studies have suggested NHEs as an effective injury prevention measure to reduce the risk of HIs [6, 82, 83]. However, the success of such programs is closely tied to player compliance [82]. While many studies have mentioned imbalances in hamstring strength between the previously injured and non-injured limbs, some research, like the study by Giakoumis et al. [84], has found no association between previous injuries and hamstring strength, indicating the complexity of this relationship. Additionally, there are no significant differences in relative force per kilogram between males and females among elite track and field athletes [84]. The Nordbord offers a quick and precise method for measuring hamstring strength and identifying imbalances, which can inform and enhance injury prevention programs.

Regarding rehabilitation from HIs, a consensus among stakeholders often involves reaching "pre-injury levels" and achieving "similar strength" as core criteria for the return to play (RTP) decision-making process [85]. Recent research has proposed HI rehabilitation protocols that focus on eccentric hamstring strengthening [9–15]. The Nordbord plays a critical role in this context, offering an accurate and objective means of assessing hamstring strength and monitoring progress on a daily basis. By using the Nordbord, therapists can ensure that the criteria for RTP are met, contributing to more effective and individualized rehabilitation programs.

In summary, the Nordbord has the potential to significantly impact injury prevention, rehabilitation, and performance monitoring in football. It provides a quantifiable and objective measurement of EKFS, which can be invaluable for stakeholders in making informed decisions related to a player's health and performance. However, further research is needed to establish normative levels of ESKF for football players at different levels and to better understand its associations with previous HIs and future injury risk.

The use of Nordbord to assess player recovery, mitigate injury risk, and enhance performance

Recovery and injury prevention are crucial aspects of maintaining player health and performance in football. Several studies have explored interventions and programs aimed at improving hamstring strength recovery and reducing the risk of injuries, with the use of Nordbord playing a significant role in these investigations.

In football, interventions such as cold-water immersion (CWI) and NHE programs have been identi-

fied as effective means to enhance recovery of EKFS and reduce the risk of HIs [6, 82, 86]. The Nordbord is a valuable tool for measuring hamstring strength and monitoring a player's response to these interventions [6], ultimately contributing to player wellbeing and performance in the sport.

Alexander et al. [86] conducted a study comparing the effects of CWI and passive rest (PR) on EKFS, isometric adductor strength, skin temperature, and subjective questionnaires. Their findings revealed significant effects for time points and groups in HES, peak torque, and peak force. The study showed that CWI had a stronger individual response compared to PR for HES, resulting in higher strength output for the CWI group, especially 24 hours post-intervention. This indicates the potential benefits of CWI in enhancing recovery and HES, which can be critical for injury prevention.

Buckthorpe et al. [87] conducted a review of HI prevention strategies and identified various risk factors contributing to HIs in football. The review highlighted that NHE programs have been effective in reducing hamstring strain injuries by 65–70%. Moreover, it emphasized that both low and high-volume NHE-based training can lead to similar adaptations in fascicle length and HES. This finding aligns with the results from Lacome et al. [56], which indicated that lower-volume, high-intensity eccentric exercises can be just as effective in preventing HIs as high-volume protocols. These insights suggest that tailored NHE programs can play a crucial role in reducing the risk of HIs and promoting player health.

As noticed, this section provides valuable insights into the use of the Nordbord device in professional football for assessing recovery, evaluating injury risk, and optimizing player performance. It also highlights the increasing physical demands of the sport and the importance of sprint ability in modern football.

In professional football, various recovery techniques are employed to optimize eccentric strength measures and knee stability during the competition phase. These techniques included massage and CWI, as studied by Rhodes [88] and Alexander et al. [86, 89]. The Nordbord can play a pivotal role in assessing player recovery after a match. It helps ensure the effectiveness of recovery methods, informs coaches about player readiness for the next match, evaluates the risk of HIs due to overuse, and assists in decision-making, especially for players who may need to participate but have physical limitations.

We should also emphasize on the changing nature of professional football, with increased speed and physical demands [90–92]. The importance of sprint ability in decisive moments, as supported by studies [93, 94], underscores the significance of optimal hamstring strength and injury prevention strategies. The increase in HIs during training over the past decade, as noted by Ekstrand [2], suggests that while injury prevention programs have been effective, the physical demands of matches have also risen. This emphasizes the need for ongoing research to adapt injury prevention methods and optimize player performance.

In summary, the use of the Nordbord in professional football is a valuable tool for assessing player recovery, mitigating the risk of injury, and enhancing performance. It is crucial in an environment where the physical demands of the sport continue to evolve, and the effectiveness of existing injury prevention programs must be continually assessed and improved.

Any issue related to conflict of interest?

The potential conflict of interest related to the involvement of one of the creators of the Nordbord in many of the published studies is a valid concern. However, it is also important to consider that scientific research is typically subject to rigorous peer review, and the findings should be evaluated based on their scientific merit and methodology rather than solely on potential conflicts of interest.

It is reassuring that other researchers, who are not directly affiliated with the Nordbord creator, have confirmed the findings and contributed to studies using the Nordbord. This multi-author and collaborative approach helps ensure that the research is subject to diverse perspectives and scrutiny.

In assessing the validity of the findings, it is essential to focus on the scientific methods, reproducibility, and the overall body of evidence rather than solely on the potential conflict of interest. This approach helps maintain the integrity and objectivity of scientific research in the field of hamstring strength assessment and injury prevention.

Table 3. A summary of the advantages and disadvantages of the Nordbord device

Advantages	Disadvantages
Fast results and automated process (approx. 30 s)	Conflicting findings in the literature regarding the validity and reliability
Highly portable	Need for standardization of the measurement process
No need for a specialized indoor lab and trained professionals	More research and data are needed to better understand the effects of fatigue on HES
Cost-effective compared to isokinetic dynamometer	A consensus is needed on the normalization of the data for body weight (N/Kg) to maximize comparability
Can be used to monitor changes in HES to help optimize performance, mitigate the risk of injuries, and inform RTP	Research is needed to establish normative levels of ESKF for football players at different levels, ages, positions, and gender, as well as the bilateral relationship between the dominant and non-dominant foot
Assist performance specialist in evaluating player fatigue levels and monitoring recovery	

A summary of the pros and cons of the Nordbord device

See table 3.

Conclusions

The objective of this paper is to examine the use of Nordbord across all football (soccer) levels and present practical recommendations concerning its application and potential limitations as a tool for measuring ESKF, given the critical role of HES in injury prevention and performance enhancement. In conclusion, the Nordbord is a cost and time-effective testing system that can be used by many professionals such as performance specialists, sports scientists, and physiotherapists, without the need for extensive training to use it. Additionally, Nordbord provides a portable and accurate method for measuring HES. In addition, the VALD performance can offer support and advice as well as a worldwide database that includes different sports and levels for comparison. It is then understandable that many professionals in several sports in the last few years have decided to include the Nordbord in their attempt to measure the ESKF, enhance performance, mitigate hamstring injury risk, and inform RTP criteria.

Practical recommendations

To optimize the utility of the Nordbord in football, several recommendations have emerged from our review. Firstly, standardized testing protocols should be established. In addition, a consensus is needed on the normalization of the data for body weight (N/Kg) to maximize the comparability across different levels of the sport to ensure consistency and comparability of the results. Furthermore, research efforts should focus on establishing normative values of ESKF tailored to various player positions, demographics, and skill levels, as well as the bilateral relationship between the dominant and non-dominant foot. Additionally, investigations into the threshold values of HES indicative of hamstring injury risk and the recovery method's effectiveness are crucial. Comparative studies should evaluate the measurements of Nordbord in relation to other devices like the gold standard isokinetic dynamometer to eliminate the uncertainty of validity and reliability. Longitudinal studies tracking ESKF changes over time, and their implications for injury risk and performance outcomes are needed. Collaboration among researchers and practitioners can foster a consensus on the best practices for Nordbord utilization and result interpretation in football.

Ethical approval

The conducted research is not related to either human or animal use.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

Funding

This research received no external funding.

Table 1. A summary of the 29 articles used in this review

Study title	Authors	Participants level	Findings
The effect of body mass on eccentric knee-flexor strength assessed with an instrumented Nordic hamstring device (Nordbord) in football players	Buchheit et al. (2016) [42]	81 soccer players (U17, U19, U21, senior 4th French division, and professionals) and 41 Australian Football League (AFL) players	Eccentric knee flexor strength measured using a Nordbord device is dependent on BM. Therefore, practitioners should use predicted scores, taking into account the BM with the actual test scores.
Anthropometric and physiological profiles of Hungarian youth male soccer players of varying ages and playing positions: a multidimensional assessment with a critical approach	Soós et al. (2022) [44]	Hungarian male soccer players belonging to different age categories 14 (n = 20), 15 (n = 16), 16 (n = 22), and 17–18 (n = 23) years	Goalkeepers displayed significantly higher scores for the dominant and non-dominant leg on the Nordbord than other outfield players. There was no difference between age groups for HES.
Examination of physical characteristics and positional differences in professional soccer players in Qatar	Wik et al. (2018) [43]	195 professional male soccer players registered with the Qatar Super League (QSL)	Defenders, when compared to goalkeepers, reported a significantly greater eccentric hamstring strength in the NHE than expected from their predicted BM-based score.
Hamstring eccentric strengthening program: does training volume matter?	Lacome et al. (2020) [56]	U19 elite French footballers	The low-volume group had similar increases in eccentric hamstring strength and changes in biceps femoris and semimembranosus fascicle lengths compared to the high-volume group over a period of 12 weeks.
Effects of high and low training volume with the nordic hamstring exercise on hamstring strength, jump height, and sprint performance in female football players: a randomised trial	Amundsen et al. (2022) [54]	Group of 45 female soccer players from two Norwegian 2nd-tier football teams	There was no difference between low and high-volume Nordic exercise protocols on maximal eccentric strength measured on Nordbord, sprinting or jump performances. Players in both groups had to adhere to the program for a minimum of 6 weeks to see significant improvements from pre- to post-interventions.
Field based lower limb strength tests provide insight into sprint and change of direction ability in academy footballers	Jones et al. (2021) [18]	146 players across different age groups from U10–U18 from one of the two English Premier League Academies	The sprint and COD performance were combined to form 'running ability'. Scaled strength (NHS and isometric hip adductor/abductor) and imbalance, when controlled for age, were associated with the running ability. The mean 505 performance was explained by age, CMJ - impulse, hip ADD, and NHS.
Including the Copenhagen adduction exercise in the FIFA 11+ provides missing eccentric hip adduction strength effect in male soccer players	Harøy et al. (2017) [55]	45 players from 2 U19 elite male soccer teams in the Oslo region	The inclusion of the Copenhagen adduction exercise in the FIFA+ program by replacing the Nordic Curl increases the hip adduction strength compared to the standard protocol. There were no improvements in sprint times for either group.
Eccentric strength assessment of hamstring muscles with new technologies: a systematic review of current methods and clinical implications	Claudin et al. (2021) [46]	17 studies included in the review with a pooled sample size of n = 2893, 97% male and 3% female	The most common parameters used were peak force (highest and average), peak torque (highest and average), and between limb imbalance (right to left ratio). There was inconsistency in the association between HES and injury risk and performance. There was no standardized definite or standardization of the calculations of the used parameters.
Assessing eccentric hamstring strength using the Nordbord: between-session reliability and inter-limb asymmetries in professional soccer players	Bishop et al. (2022) [48]	14 professional football players from the first team of a professional club in the UK	Intraclass correlation coefficients showed moderate levels of between-session reliability (ICC: 0.69–0.73), for relative reliability, the CVs were < 10% across 4 weeks with the exception of the dominant limb in sessions 1–2. When determining systematic bias, no meaningful changes were observed in peak force on either limb or magnitude of asymmetry.
Effects of the Nordic hamstring exercise on sprint capacity in male football players: a randomized controlled trial	Ishøi et al. (2018) [20]	35 amateur male players (age 17–25)	Randomized controlled trial with an intervention group (N = 18) following a 10-week supervised strength training of NHE with progressive overload. Between-group differences in mean changes were observed in favor of the IG for sprint performance outcomes; TST (–0.649 s, p = 0.056, d = 0.38), 10mST (–0.047 s, p = 0.005, d = 0.64), L10mST (–0.052 s, p = 0.094, d = 0.59), and for strength outcomes; ECC-PHS (62.3 N, p = 0.006, d = 0.92) and ECC-CAPHS (951 N, p = 0.005, d = 0.95).

Asymmetry thresholds for common screening tests and their effects on jump performance in professional soccer players	Read et al. (2021) [51]	203 professional soccer players (age 24.4 + 6, 4.7 years, height: 175.7 + 6, 6.6 cm, BM: 71.5 + 6, 9.3 kg)	This study aimed to establish normative and positional asymmetry values used in a screening test and examine their relationships with jumping performance. A large variability (5.2%–14.5%) was reported in asymmetry scores across different tests and physical qualities. The HAM and QUAD composite scores indicated that Q4 player jumps were shorter than those in other quartiles during a single-legged countermovement jump and 10-second hop (p, 0.05). No decrements in unilateral jump performance were shown among players in each quartile for a range of motion or hip-adduction and abduction strength, and no composite measurements of asymmetry affected bilateral jump performance.
Effects of small-sided game variation on changes in hamstring strength	Madison et al. (2019) [67]	10 semi-professional male soccer players (age: 23 + 5 yrs, stature: 178 + 7 cm, BM: 73.4 + 10.6 kg)	Comparison between small and large relative areas of small-sided games of football on the hamstring torque measured on the Nordbord. There were differences ($p < 0.05$) between the small and large relative area games for peak hamstring force decrement (5.78 N and 213.62 N, respectively) and mean hamstring force decrement at 908 (11.11 N and 24.78 N, respectively). The number of accelerations was related to ($r = 0.46$, $p = 0.039$) reduced hamstring peak torque at 908. Larger relative area SSG create greater internal and external loads causing decrements in hamstring force.
The effects of a soccer-specific fitness test on eccentric knee flexor strength	Brogden et al. (2020) [66]	67 academy players age: 16.58 (0.57) yrs, height: 175.45 (5.85) cm, body weight: 66.30 (8.21) kg	The objective was to examine the effect of YYIR 1 on eccentric knee flexor strength on the Nordbord. Paired *t*-tests highlighted increased absolute eccentric knee flexor strength values ($p < 0.001$) immediately post-YYIR1 for both the dominant and non-dominant limbs, with the same trend ($p < 0.001$) observed for eccentric strength relative to BM. In conclusion, the YYIR 1 does not induce eccentric knee flexor fatigue and is not a valid assessment method to examine the effects of fatigue on hamstring function.
Unilateral vs. bilateral hamstring strength assessments: comparing reliability and inter-limb asymmetries in female soccer players	Cuthbert et al. (2021) [52]	29 female soccer players (age: 21.1 + 4.5 years; height: 169.7 + 5.8 cm; BM: 66.2 + 6.4 kg)	This study aimed to assess reliability for two unilateral and two bilateral field-based hamstring assessments. The absolute reliability of most methods was acceptable (< 10%). Relative reliability within sessions was fair to excellent (ICC ≥ 0.784; lower bound 95% CI ≥ 0.623). Greater variability in between-sessions relative reliability was observed during the unilateral tests, demonstrating poor to good (ICC = 0.698–0.798; lower bound 95% CI = 0.274–0.638). Bilateral assessments demonstrated similar ranges of poor to excellent (ICC = 0.679–0.963; lower bound 95% CI = 0.231–0.790). In conclusion, the NHE was the most reliable within and between sessions, demonstrating substantial agreement in asymmetry between sessions.
Quantification of eccentric hamstrings strength in elite academy footballers: considerations for assessment	Rhodes et al. (2022) [49]	21 elite youth footballers from Premier League Category 1 Academy (age: 17.63 + 0.76 yrs, height: 180.2 + 6.1 cm, BM: 72.5 + 9.9 kg)	This study aimed to identify the reliability of eccentric strength metrics measured using isokinetic dynamometry and Nordbord. The test-retest of both devices identified significant correlations for all eccentric strength metrics ($p \leq 0.05$). Significant unilateral (L) relationships between PT, AvT (IKD $60° \cdot s^{-1}$; $180° \cdot s^{-1}$), break angle (Θ) (Nordbord) angle, and peak torque at $60° \cdot s^{-1}$ and Θ were identified ($p \leq 0.05$). In conclusion, the eccentric hamstring strength assessment done on both devices provided reliable information.

The influence of weekly sprint volume and maximal velocity exposures on eccentric hamstring strength in professional football players	Shah et al. (2022) [68]	58 male professional footballers	The objective was to examine the relationship between sprinting and eccentric hamstring strength by monitoring total weekly sprint volume and distance at > 90% and > 95% of maximum velocity. Weekly sprint distances (p = 0.13, p < 0.01) and weekly efforts > 90% of maximum velocity (p = 0.08, p = 0.01) displayed significant inverse relationships with the percentage change in eccentric hamstring strength; weekly efforts > 95% of maximum velocity showed no relationship with hamstring strength (p = 0.02, p = 0.45). Only weekly efforts > 90% of maximum velocity significantly influenced the mean percentage change in eccentric hamstring force, $F(3,58)$ = 3.71, p = 0.01, with significant differences occurring when comparing 7–8 sprint efforts with 0–2 efforts (0.11%, p = 0.03) and 5–6 efforts (0.12%, p = 0.03). In conclusion, the eccentric hamstring strength levels significantly decrease when 7–8 weekly sprints are completed at > 90% max velocity.
Recommendations for hamstring injury prevention in elite football: translating research into practice	Buckthorpe et al. (2019) [87]	N/A	In this review, the authors listed the risk factors linked to hamstring strain injuries either through prospective, retrospective, or anecdotal evidence. They then formulated a five-point strategy for hamstring strain injury prevention in elite football involving the role of strength training and hip stability to training load and recovery balance.
Utilization of performance markers to establish the effectiveness of cold-water immersion as a recovery modality in elite football	Alexander et al. (2022) [86]	Twenty-four elite footballers (age: 20.58 ± 2.55 years; height: 179.9 ± 5.6 cm; weight: 75.7 ± 7.5 kg; body fat: 6.2 ± 1.7%)	The authors investigated the effects of cold-water immersion on eccentric hamstring strength and hamstring flexibility, and isometric adductor strength, along with subjective assessments of wellbeing. Linear regression for individual analyses demonstrated greater recovery in peak torque and force for CWI. CWI may be useful to ameliorate potential deficits in eccentric hamstring strength that optimize readiness to train/play in elite football settings.
Comprehensive training load monitoring with biomarkers, performance testing, local positioning data, and questionnaires – first results from elite youth soccer	Haller et al. (2022) [79]	Eight male players (mean ± *SD*: age: 17.0 ± 0.6 years, weight: 69.6 ± 8.2 kg, height: 177 ± 7 cm, VO_2max: 62.2 ± 3.8 ml/min/kg)	In this four-week pilot study, the authors attempted to assess the feasibility and acceptance of an extensive monitoring approach using biomarkers, neuromuscular performance, and questionnaires in an elite soccer setting. Strength testing included NHE and hip abduction to adduction. Feasibility was high with no impact on the training schedule and no adverse effects of injuries during the assessments. Occasional significant correlations were observed between questionnaire scores, training load data, and neuromuscular performance.
The relationship between previous lower extremity injury, body weight and bilateral eccentric hamstring strength imbalance in young soccer players	Isik et al. (2018) [77]	88 male soccer players from first division teams in Turkey (U14–U19)	This study aimed to investigate the effects of lower limb injuries on bilateral HES imbalance and to find out if there is a relationship between BW and HSI. There were significant relationships between BW and HSI (p < 0.05, 0.04 > r > 0.02) and non-significant results for HSI ($F(1.85)$ = 0.578, p > 0.05). However, the effect of BW was significant for HSI ($F(1.85)$ = 3.91, p < 0.05, η^2 = 0.068). The key finding is that players reporting lower limb injuries had similar eccentric HSI in comparison to non-injured players.
Strength development and non-contact lower limb injury in academy footballers across age groups	Jones et al. (2021)	195 contracted players in category 1 and 2 Premier League football academies in England. 143 players completed the study from U10–U18	This study investigated the impact of non-contact lower limb injury on hip, groin, and knee flexor strength development. The players who sustained NCLLI were compared to those who did not. There was no difference in any lower limb strength assessments between injured and non-injured academy footballers when controlled for baseline measures. There was a decline in strength during the season for stronger footballers and weaker players gained strength across the season.

Strength, power and speed characteristics in elite academy soccer	Sherwood et al. (2021) [45]	64 academy male soccer players (U16s: *n* = 18, U18s: *n* = 22, and U23s: *n* = 24)	This study highlighted strength, power, and speed characteristics, comparing these metrics between age groups and determined the relationship between lower body strength, eccentric hamstring strength, upper body strength, and sprint and jump performance. The analysis of variance showed that age category had a significant effect on height, mass, countermovement jump, left eccentric hamstring strength, right eccentric hamstring strength, average eccentric hamstring strength, 20 m sprint speed, estimated one repetition maximum squat absolute and relative, and estimated one repetition maximum bench press absolute. In the U16s age group, there was a significant relationship between 10 m sprint and absolute squat strength (r = –0.759), and 20m sprint speed and absolute squat strength (r = –0.757). In the U23s age group, there was a significant relationship between 10 m sprint speed and relative squat strength (r = –0.598) and 20m sprint speed and relative squat strength (r = –0.653).
The influence of maturation on the reliability of the Nordic hamstring exercise in male youth footballers	Fernandes et al. (2020) [50]	64 male youth footballers from U11 (*n* = 17, age: 10.8 + 0.3 yrs, weight: 42.0 + 3.7 kg, stature: 148.6 + 2.8), U13 (*n* = 29, age 12.1 + 0.7, weight: 39.6 + 2.5 kg, stature: 149.2 + 4.7 cm), and U16 (*n* = 18, age: 15.4 + 0.4 yrs, weight: 63.7 + 6.6 kg, stature: 173.9 + 6.7)	The study sought to determine the reliability of the NHE. The players were categorized via maturity offset based on PHV and age. Reliability for left, right, bilateral, and relative peak force for the U11s (TE = 0.26 to 11.1N, coefficient of variation (CV) = 5.9 to 7.4%), U13s (TE = 0.28 to 17.9N, CVs = 5.6 to 7.8%), and U16s (TE = 0.28 to 24.3, CVs = 6.6 to 8.7%) was favorable and demonstrated no clear pattern between groups. For all age and maturation groups, imbalances yielded poor reliability (TE = 7.1 to 10.8 N, CVs = 33.1 to 38.3%).
Influence of maturation status on eccentric hamstring strength improvements in youth male soccer players after the Nordic hamstring exercise	Drury et al. (2020) [59]	48 youth male soccer players separated into pre-PHV (11.0 [0.9] yrs) or mid/post-PHV (13.9 [1.1] yrs)	This study examined the effects of a 6-week NHE program on less mature and more mature players based on their PHV status. Pre-PHV (d = 0.83 [0.03–1.68]) and post-PHV (d = 0.53 [–0.06–1.12]) experimental groups showed moderate to small increases in relative eccentric hamstring strength. Moderate increases in the same measure were also seen in the between-groups analyses in the pre-PHV (d = 1.03 [0.23–1.84]) and mid-PHV (d = 0.87 [0.22–1.51]) groups, with a greater effect observed in the former.
Strength and biomechanical risk factors for non-contact ACL injury in elite female footballers: a prospective study	Collings et al. (2022) [78]	322 elite senior and junior female Australian Rules and soccer players, 277 were selected for the final data collection and analysis	The aim was to determine if a field-based battery of tests, including the eccentric knee flexor strength measurement using a Nordbord, was prospectively associated with non-contact ACL injuries. A total of 15 ACL injuries occurred during the study period, prior ACL injury (odds ratio [OR] = 9.68, 95% CI = 2.67–31.46), a lower isometric hip adductor to abductor strength ratio (OR = 1.98, 95% CI = 1.09–3.61), greater CMJ peak take-off force (OR = 1.74, 95% CI = 1.09–3.61), greater single-leg triple vertical hop average dynamic knee valgus (OR = 1.97, 95% CI = 1.06–3.63), and ipsilateral trunk flexion (OR = 1.60, 95% CI = 1.01–2.55) were independently associated with increased risk for subsequent ACL injury. Between leg asymmetry in the lower limbs and CMJ kinetics were not associated with the ACL injury risk. However, non-directional between-leg asymmetry for ESKF had a significant odds ratio, suggesting that imbalances in ESKF may be associated with an increased risk of non-contact ACL injuries.
The relationship between eccentric hamstring strength and dynamic stability in elite academy footballers	Rhodes et al. (2021) [70]	59 elite academy male footballers from two premier league category 1-status academies (age: 17.89 + 2.29 yrs, height: 180.40 + 7.93 cm, and weight: 73.65 + 6.38 kg)	This study aimed to observe the relationship between dynamic stability and eccentric strength. Significant correlations were identified bilaterally for functional hamstring strength metrics and PM and PL stability ($p \leq 0.05$). No significant relationships were identified between anterior stability and eccentric hamstring strength parameters ($p > 0.05$). In conclusion, eccentric hamstring strength had a positive influence on the directional stability of the posteromedial and posterolateral planes.

Association between hamstrings' eccentric strength and sprint performance in football players	Brünn et al. (2022) [69]	48 professional footballers from the Slovak top-tier football league (age: 23.15 + 4.78 yrs, height: 180.5 + 5.42 cm, weight: 76.5 + 7.94 kg)	This study aimed to observe the correlation between 30 m sprints and eccentric hamstring strength measured on a Nordbord. The correlation between 30 m performance and average eccentric hamstring strength was –0.0826. The correlation suggests that the sprint speed and eccentric strength of the hamstrings are not associated with 0 (t = –0.5619; df = 46; p = 0.5769). The authors warranted the need for more interventional studies to establish these findings.
Profile of the muscular strength of hamstring in soccer players of the Colombian Professional League monitored with Nordbord technology	Quiceno et al. (2020) [57]	20 male players from a professional football club in Colombia	This study examined the effects of a 24-week, biweekly intervention program of bilateral NHE in male professional players. No significant (p = 0.258) changes were observed after the intervention. Results in absolute values of HES for post and after interventions are given to different positions. Central defenders had the highest average and wingers the lowest.
Effect of an injury prevention program on the muscular strength of colombian professional female soccer players	Quiceno et al. (2021) [58]	21 Adult female professional football players (20–32 yrs) from the first division of Colombia, without muscle injuries in the past 2 months	This study examined the effects of an 8-week, biweekly intervention program of bilateral NHE in female professional players. The results showed a significant (p < 0.0001) increase between pre- and post-intervention on ESKFs. The median values increased from 174 N to 216 N.

N/A – not available

References

[1] Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). Am J Sports Med. 2011;39(6):1226–32; doi: 10.1177/0363546510395879.
[2] Ekstrand J, Lee JC, Healy JC. MRI findings and return to play in football: a prospective analysis of 255 hamstring injuries in the UEFA Elite Club Injury Study. Br J Sports Med. 2016;50(12):738–73; doi: 10.1136/bjsports-2016-095974.
[3] Taberner M, Haddad FS, Dunn A, Newall A, Parker L, Betancur E, Cohen DD. Managing the return to sport of the elite footballer following semimembranosus reconstruction. BMJ Open Sport Exerc Med. 2020;6(1):e000898; doi: 10.1136/bmjsem-2020-000898.
[4] Read PJ, Oliver JL, De Ste Croix MBA, Myer GD, Lloyd RS. An audit of injuries in six english professional soccer academies. J Sports Sci. 2018; 36(13):1542–8; doi: 10.1080/02640414.2017.1402535.
[5] Vicens-Bordas J, Esteve E, Fort-Vanmeerhaeghe A, Casals M, Bandholm T, Ishoi L, Opar D, Shield A, Thorborg K. 160 Eccentric hamstring strength and sprinting performance changes during the off-season in Spanish footballers. Br J Sports Med. 2021: 55(Suppl 1):A63.2-A64; doi: 10.1136/bjsports-2021-ioc.148.
[6] Brukner P. Hamstring injuries: prevention and treatment-an update. Br J Sports Med. 2015;49(19): 1241–4; doi: 10.1136/bjsports-2014-094427.
[7] Opar DA, Williams MD, Timmins RG, Hickey J, Duhig SJ, Shield AJ. Eccentric hamstring strength and hamstring injury risk in Australian footballers. Med Sci Sports Exerc. 2015;47(4):857–65; doi: 10.1249/MSS.0000000000000465.
[8] Bourne MN, Opar DA, Williams MD, Shield AJ. Eccentric knee flexor strength and risk of hamstring injuries in rugby union: a prospective study. Am J Sports Med. 2015;43(11):2663–70; doi: 10.1177/0363546515599633.
[9] Valle X, L Tol J, Hamilton B, Rodas G, Malliaras P, Malliaropoulos N, Rizo V, Moreno M, Jardi J. Hamstring muscle injuries, a rehabilitation protocol purpose. Asian J Sports Med. 2015;6(4):e25411; doi: 10.5812/asjsm.25411.
[10] Mendiguchia J, Martinez-Ruiz E, Edouard P, Morin J-B, Martinez-Martinez F, Idoate F, Mendez-Villanueva A. A multifactorial, criteria-based progressive algorithm for hamstring injury treatment. Med Sci Sports Exerc. 2017;49(7):1482–92; doi: 10.1249/MSS.0000000000001241.
[11] Tyler TF, Schmitt BM, Nicholas SJ, McHugh MP. Rehabilitation after hamstring-strain injury emphasizing eccentric strengthening at long muscle lengths: results of long-term follow-up. J Sport Rehabil. 2017;26(2):131–40; doi: 10.1123/jsr.2015-0099.
[12] Macdonald B, McAleer S, Kelly S, Chakraverty R, Johnston M, Pollock N. Hamstring rehabilitation in elite track and field athletes: applying the British Athletics Muscle Injury Classification in clin-

ical practice. Br J Sports Med. 2019;53(23):1464–73; doi: 10.1136/bjsports-2017-098971.
[13] Palermi S, Massa B, Vecchiato M, Mazza F, De Blasiis P, Romano AM, Di Salvatore MG, Della Valle E, Tarantino D, Ruosi C, Sirico F. Indirect structural muscle injuries of lower limb: rehabilitation and therapeutic exercise. J Funct Morphol Kinesiol. 2021;6(3):75; doi: 10.3390/jfmk6030075.
[14] Rudisill SS, Kucharik MP, Varady NH, Martin SD. Evidence-based management and factors associated with return to play after acute hamstring injury in athletes: a systematic review. Orthop J Sports Med. 2021;9(11):23259671211053830; oi: 10.1177/23259671211053833.
[15] Hickey JT, Opar DA, Weiss LJ, Heiderscheit BC. Hamstring strain injury rehabilitation. J Athl Train. 2022;57(2):125–35; doi: 10.4085/1062-6050-0707.20.
[16] Stastny P, Lehnert M, Tufano JJ. Muscle imbalances: testing and training functional eccentric hamstring strength in athletic populations. J Vis Exp. 2018;(135); doi: 10.3791/57508; doi: 10.3791/57508.
[17] Mendiguchia J, Martinez-Ruiz E, Morin JB, Samozino P, Edouard P, Alcaraz PE, Esparza-Ros F, Mendez-Villanueva A. Effects of hamstring-emphasized neuromuscular training on strength and sprinting mechanics in football players. Scand J Med Sci Sports. 2015;25(6):e621–9; doi: 10.1111/sms.12388.
[18] Jones S, Mullen R, Clair Z, Wrigley R, Andersen TE, Williams M. Field based lower limb strength tests provide insight into sprint and change of direction ability in academy footballers. Scand J Med Sci Sports. 2021;31(12):2178–86; doi: 10.1111/sms.14039.
[19] Mjølsnes R, Arnason A, Østhagen T. A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. Scand J Med Sci Sports 14(5): 311–7; doi: 10.1046/j.1600-0838.2003.367.x.
[20] Ishøi L, Hölmich P, Aagaard P, Thorborg K, Bandholm T, Serner A. Effects of the Nordic hamstring exercise on sprint capacity in male football players: a randomized controlled trial. J Sports Sci. 2018;36(14):1663–72; doi: 10.1080/02640414.2017.1409609.
[21] Siddle J, Greig M, Weaver K, Page RM, Harper D, Brogden CM. Acute adaptations and subsequent preservation of strength and speed measures following a Nordic hamstring curl intervention: a randomised controlled trial. J Sports Sci. 2019;37(8): 911–20; doi: 10.1080/02640414.2018.1535786.
[22] Bautista IJ, Vicente-Mampel J, Baraja-Vegas L, Segarra V, Martín F, Van Hooren B. The effects of the Nordic hamstring exercise on sprint performance and eccentric knee flexor strength: a systematic review and meta-analysis of intervention studies among team sport players. J Sci Med Sport. 2021;24(9):931–8; doi: 10.1016/j.jsams.2021.03.009.
[23] Small K, McNaughton L, Greig M, Lovell R. Effect of timing of eccentric hamstring strengthening exercises during soccer training: implications for muscle fatigability. J Strength Cond Res. 2009; 23(4):1077–83; doi: 10.1519/JSC.0b013e318194df5c.
[24] Stark T, Walker B, Phillips JK, Fejer R, Beck R. Handheld dynamometry correlation with the gold standard isokinetic dynamometry: a systematic review. PM R. 2011;3(5):472–9; doi: 10.1016/j.pmrj.2010.10.025.
[25] Katoh M, Hiiragi Y, Uchida M. Validity of isometric muscle strength measurements of the lower limbs using a handheld dynamometer and belt: a comparison with an isokinetic dynamometer. J Phys Therapy Sci. 2011;23(4):553–7; doi: 10.1589/jpts.23.553.
[26] Ieiri A, Tushima E, Ishida K, Inoue M, Kanno T, Masuda T. Reliability of measurements of hip abduction strength obtained with a handheld dynamometer. Physiother Theory Pract. 2015;31(2): 146–52; doi: 10.3109/09593985.2014.960539.
[27] Muff G, Dufour S, Meyer A, Severac F, Favret F, Geny B, Lecocq J, Isner-Horobeti M-E. Comparative assessment of knee extensor and flexor muscle strength measured using a handheld vs. isokinetic dynamometer. J Phys Therapy Sci. 2016; 28(9):2445–51; doi: 10.1589/jpts.28.2445.
[28] Bohannon RW. Test-retest reliability of handheld dynamometry during a single session of strength assessment. Phys Ther. 1986;66(2):206–9; doi: 10.1093/ptj/66.2.206.
[29] Whiteley R, Jacobsen P, Prior S, Skazalski C, Otten R, Johnson A. Correlation of isokinetic and novel handheld dynamometry measures of knee flexion and extension strength testing. J Sci Med Sport. 2012;15(5):444–50; doi: 10.1016/j.jsams.2012.01.003.
[30] Chamorro C, Armijo-Olivo S, De la Fuente C, Fuentes J, Javier Chirosa L. Absolute reliability and concurrent validity of hand held dynamometry and isokinetic dynamometry in the hip, knee

and ankle joint: systematic review and meta-analysis. Open Med. 2017;12:359–75; doi: 10.1515/med-2017-0052.

[31] Mellor L. NordBord: EPL, NBA and NFL clubs sign up for Brisbane invention that predicts hamstring injuries. abc.net.au. 2016. Available from: https://www.abc.net.au/news/2016-02-17/epl-afl-nfl-nba-sign-up-for-brisbane-nordbord/7177640?utm_campaign=abc_news_web&utm_content=link&utm_medium=content_shared&utm_source=abc_news_web (accessed February 17, 2016).

[32] Rains B. The NordBord is seeing success in preventing hamstring injuries and saving teams fortunes. Sports Business J. 2016. Available from: https://www.sportsbusinessjournal.com/Daily/Issues/2016/02/23/Technology/the-nordbord-is-seeing-success-in-preventing-hamstring-injuries-and-saving-teams-fortunes.aspx (accessed February 23, 2016).

[33] VALD performance. VALD Performance Human Measurement Technologies. 2020. Available from: http://valdperformance.com (accessed October 01, 2023).

[34] VALD performance. VALD performance. Available from: https://valdperformance.com (accessed 2024).

[35] Opar DA, Piatkowski T, Williams MD, Shield AJ. A novel device using the Nordic hamstring exercise to assess eccentric knee flexor strength: a reliability and retrospective injury study. J Orthop Sports Phys Ther. 2013;43(9):636–40; doi: 10.2519/jospt.2013.4837.

[36] Torpey D, Murray E, Hughes T, Sergeant J, Callaghan M. The reliability of and agreement between devices used to measure eccentric hamstring strength: a systematic review protocol. Syst Rev. 2022;11(1):204; doi: 10.1186/s13643-022-02070-8.

[37] Green B, Bourne MN, Pizzari T. Isokinetic strength assessment offers limited predictive validity for detecting risk of future hamstring strain in sport: a systematic review and meta-analysis. Br J Sports Med. 2018;52(5):329–36; doi: 10.1136/bjsports-2017-098101.

[38] Miralles-Iborra A, Elvira JLL, Urban T, Calado A, Del Coso J, Moreno-Pérez V. Agreement between isokinetic eccentric hamstring strength, Nordic hamstring strength and Nordic break-point angle in a sample of trained and healthy individuals. Eur J Sport Sci. 2023;23(2):155–64; doi: 10.1080/17461391.2021.2014984.

[39] Sconce E, Jones P, Turner E, Comfort P, Graham-Smith P. The validity of the Nordic hamstring lower for a field-based assessment of eccentric hamstring strength. J Sport Rehabil. 2015;24(1):13–20; doi: 10.1123/JSR.2013-0097.

[40] Cotter R. A Review of the NordBord Hamstring Testing System. Available from: https://simplifaster.com/articles/review-nordbord-hamstring-testing-system/ (accessed January 05, 2017).

[41] Luchner R, Steidl-Müller L, Niedermeier M, Raschner C. Maximal isometric or eccentric hamstring strength-which test modality might be more suitable for assessments in youth alpine ski racers? Int J Environ Res Public Health. 2021;18(4):2138; doi: 10.3390/ijerph18042138.

[42] Buchheit M, Cholley Y, Nagel M, Poulos N. The effect of body mass on eccentric knee-flexor strength assessed with an instrumented Nordic hamstring device (Nordbord) in football players. Int J Sports Physiol Perform. 2016;11(6):721–6; doi: 10.1123/ijspp.2015-0513.

[43] Wik EH, Auliffe SM, Read PJ. Examination of physical characteristics and positional differences in professional soccer players in Qatar. Sports. 2018;7(1):9; doi: 10.3390/sports7010009.

[44] Soós I, Borysławski K, Boraczyński M, Ihasz F, Podstawski R. Anthropometric and physiological profiles of hungarian youth male soccer players of varying ages and playing positions: a multidimensional assessment with a critical approach. Int J Environ Res Public Health. 2022;19(17):11041; doi: 10.3390/ijerph191711041.

[45] Sherwood CN, Read P, Till K, Paxton K, Keenan J, Turner AN. Original scientific research study strength, power and speed characteristics in elite academy soccer. J Australian Strength Cond. 2021;29(2):13–22.

[46] Claudino JG, Cardoso Filho CA, Bittencourt NFN, Gonçalves LG, Couto CR, Quintão RC, Reis GF, de Oliveira Júnior O, Amadio AC, Boullosa D, Cerca Serrão J. Eccentric strength assessment of hamstring muscles with new technologies: a systematic review of current methods and clinical implications. Sports Med Open. 2021;7(1):10; doi: 10.1186/s40798-021-00298-7.

[47] Ogborn DI, Bellemare A, Bruinooge B, Brown H, McRae S, Leiter J. Comparison of common methodologies for the determination of knee flexor muscle strength. Int J Sports Phys Ther. 2021;16(2):350–9; doi: 10.26603/001c.21311.

[48] Bishop C, Manuel J, Drury B, Beato M, Turner A. Assessing eccentric hamstring strength using the Nordbord: between-session reliability and inter-limb asymmetries in professional soccer players.

J Strength Cond Res. 2022;36(9):2552–7; doi: 10.1519/JSC.0000000000004303.
[49] Rhodes D, Greig M, Jeffrey J, Alexander J. Quantification of eccentric hamstrings strength in elite academy footballers: considerations for assessment. Cent Eur J Sport Sci Med. 2022;39(3):5–16; doi: 10.18276/cej.2022.3-01.
[50] Fernandes JFT, Moran J, Clarke H, Drury B. The influence of maturation on the reliability of the Nordic hamstring exercise in male youth footballers. Transl Sports Med. 2020;3(2):148–53; doi: 10.1002/tsm2.124.
[51] Read PJ, McAuliffe S, Bishop C, Oliver JL, Graham-Smith P, Farooq MA. Asymmetry thresholds for common screening tests and their effects on jump performance in professional soccer players. J Athl Train. 2021;56(1):46–53; doi: 10.4085/1062-6050-0013.20.
[52] Cuthbert M, Comfort P, Ripley N, McMahon JJ, Evans M, Bishop C. Unilateral vs. bilateral hamstring strength assessments: comparing reliability and inter-limb asymmetries in female soccer players. J Sports Sci. 2021;39(13):1481–8; doi: 10.1080/02640414.2021.
[53] O'Brien J, Browne D, Earls D, Lodge C. Reliability of the hip extension lower exercise as a measure of eccentric hamstring strength. Biomechanics. 2022; 2:1–6; doi: 10.3390/biomechanics2010001.
[54] Amundsen R, Heimland JS, Thorarinsdottir S, Møller M, Bahr R. Effects of high and low training volume with the nordic hamstring exercise on hamstring strength, jump height, and sprint performance in female football players: a randomised trial. Transl Sports Med. 2022;2022:7133928; doi: 10.1155/2022/7133928.
[55] Harøy J, Thorborg K, Serner A, Bjørkheim A, Rolstad LE, Hölmich P, Bahr R, Andersen TE. Including the Copenhagen adduction exercise in the FIFA 11+ provides missing eccentric hip adduction strength effect in male soccer players: a randomized controlled trial. Am J Sports Med. 2017; 45(13):3052–9; doi: 10.1177/0363546517720194.
[56] Lacome M, Avrillon S, Cholley Y, Simpson BM, Guilhem G, Buchheit M. Hamstring eccentric strengthening program: does training volume matter? Int J Sports Physiol Perform. 2020;15:81–90; doi: 10.1123/ijspp.2018-0947.
[57] Quiceno C, Mantilla A, Iván J, Samudio MA. Profile of the muscular strength of hamstring in soccer players of the Colombian Professional League monitored with Nordbord technology [in Spanish]. Kronos. 2020:19(2).
[58] Quiceno C, Mantilla JIA, Samudio MA, Del Castillo D. Effect of an injury prevention program on the muscular strength of colombian professional female soccer players [in Spanish]. RICCAFD. 2021;10(2):1–17; doi: 10.24310/riccafd.2021.v10i2.11323.
[59] Drury B, Green T, Ramirez-Campillo R, Moran J. Influence of maturation status on eccentric hamstring strength improvements in youth male soccer players after the Nordic hamstring exercise. Int J Sports Physiol Perform. 2020;1–7: :990–6; doi: 10.1123/ijspp.2019-0184.
[60] Jones S, Clair Z, Wrigley R, Mullen R, Andersen TE, Williams M. Strength development and non-contact lower limb injury in academy footballers across age groups. Scand J Med Sci Sports. 2021; 31(3):679–90; doi: 10.1111/sms.13889.
[61] Opar DA, Williams MD, Timmins RG, Hickey J, Duhig SJ, Shield AJ. The effect of previous hamstring strain injuries on the change in eccentric hamstring strength during pre-season training in elite Australian footballers. Am J Sports Med. 2015;43(2):377–84; doi: 10.1177/0363546514556638.
[62] Kumagai K, Abe T, Brechue WF, Ryushi T, Takano S, Mizuno M. Sprint performance is related to muscle fascicle length in male 100-m sprinters. J Appl Physiol. 2000;88(3):811–6; doi: 10.1152/jappl.2000.88.3.811.
[63] Mendiguchia J, Conceição F, Edouard P, Fonseca M, Pereira R, Lopes H, Morin J-B, Jiménez-Reyes P. Sprint versus isolated eccentric training: Comparative effects on hamstring architecture and performance in soccer players. PLOS ONE. 2020;15(2):e0228283; doi: 10.1371/journal.pone.0228283.
[64] Behan F, Vermeulen R, Whiteley R, Timmins R. The dose response of Nordic hamstring exercises on biceps femoris long head architecture and eccentric hamstring strength. J Sci Med Sport. 2019; 22(Suppl 2):71–2; doi: 10.1016/j.jsams.2019.08.284.
[65] Freeman B, James L, Opar D, Tapley S, Young W. A comparison of acceleration and maximum speed sprint training on eccentric hamstring strength and hamstring muscle architecture. J Sci Med Sport. 2021;24(Suppl 1):6–7; doi: 10.1016/j.jsams.2021.09.025.
[66] Brogden CM, Gough L, Kelly A. The effects of a soccer-specific fitness test on eccentric knee flexor strength. J Sport Rehabil. 2020;30(4):568–72; doi: 10.1123/jsr.2019-0532.

[67] Madison G, Patterson SD, Read P, Howe L, Waldron M. Effects of small-sided game variation on changes in hamstring strength. J Strength Cond Res. 2019;33(3):839–45; doi: 10.1519/JSC.0000000000002955.
[68] Shah S, Collins K, Macgregor LJ. The influence of weekly sprint volume and maximal velocity exposures on eccentric hamstring strength in professional football players. Sports. 2022;10(8):125; doi: 10.3390/sports10080125.
[69] Brünn D, Líška D, Švantner R, Franek V, Sýkora J, Pupiš M. Association between hamstrings eccentric strength and sprint performance in football players. Sport Mont. 2022;20(2):103–9; doi: 10.26773/smj.220616.
[70] Rhodes D, Jeffrey J, Maden-Wilkinson J, Reedy A, Morehead E, Kiely J, Birdsall D, Carling C, Alexander J. The relationship between eccentric hamstring strength and dynamic stability in elite academy footballers. Sci Med Footb. 2021;5(1):48–54; doi: 10.1080/24733938.2020.1782458.
[71] Draganidis D, Chatzinikolaou A, Avloniti A, Barbero-Álvarez JC, Mohr M, Malliou P, Gourgoulis, Deli CK, Douroudos II, Margonis K, Gioftsidou A, Flouris AD, Jamurtas AZ, Koutedakis Y, Fatouros IG. Recovery kinetics of knee flexor and extensor strength after a football match. PLOS ONE. 2015;10(6):e0128072; doi: 10.1371/journal.pone.0128072.
[72] Matthews MJ, Heron K, Todd S, Tomlinson A, Jones P, Delextrat A, Cohen DD. Strength and endurance training reduces the loss of eccentric hamstring torque observed after soccer specific fatigue. Phys Ther Sport. 2017;25:39–46; doi: 10.1016/j.ptsp.2017.01.006.
[73] Kakavas G, Kekelekis A. 310 The effect of a 90-min soccer match and fatigue on eccentric hamstring strength: implications for hamstring injury risk. Br J Sports Med. 2021;55(Suppl 1):A119; doi: 10.1136/bjsports-2021-IOC.284.
[74] Salter J, Cresswell R, Forsdyke D. The impact of simulated soccer match-play on hip and hamstring strength in academy soccer players. Sci Med Footb. 2022;6(4):465–72; doi: 10.1080/24733938.2021.1973080.
[75] Greig M. Concurrent changes in eccentric hamstring strength and knee joint kinematics induced by soccer-specific fatigue. Phys Ther Sport. 2019;37:21–6; doi: 10.1016/j.ptsp.2019.02.003.
[76] Dewig DR, Goodwin JS, Pietrosimone BG, Blackburn JT. Associations among eccentric hamstrings strength, hamstrings stiffness, and jump-landing biomechanics. J Athl Train. 2020;55(7):717–23; doi: 10.4085/1062-6050-151-19.
[77] Isik A, Unlu G, Batin Gozubuyuk O, Aslanyurek T, Bereceli C. The relationship between previous lower extremity injury, body weight and bilateral eccentric hamstring strength imbalance in young soccer players. Montenegrin J Sports Sci Med. 2018;7(2):23–8; doi: 10.26773/mjssm.180904.
[78] Collings TJ, Diamond LE, Barrett RS, Timmins RG, Hickey JT, DU Moulin WS, Morgan MD, Beerworth KA, Bourne MN. Strength and biomechanical risk factors for non-contact ACL injury in elite female footballers: a prospective study. Med Sci Sports Exerc. 2022;54(8):1242–51; doi: 10.1249/MSS.0000000000002908.
[79] Haller N, Blumkaitis JC, Strepp T, Schmuttermair A, Aglas L, Simon P, Neuberger E, Kranzinger C, Kranzinger S, O'Brien J, Ergoth B, Raffetseder S, Fail C, Düring M, Stöggl T. Comprehensive training load monitoring with biomarkers, performance testing, local positioning data, and questionnaires – first results from elite youth soccer. Front Physiol. 2022;13:1000898; doi: 10.3389/fphys.2022.1000898.
[80] Lee JWY, Mok K-M, Chan HCK, Yung PSH, Chan K-M. Eccentric hamstring strength deficit and poor hamstring-to-quadriceps ratio are risk factors for hamstring strain injury in football: a prospective study of 146 professional players. J Sci Med Sport. 2018;21(8):789–93; doi: 10.1016/j.jsams.2017.11.017.
[81] Opar D, Williams M, Timmins R, Hickey J, Duhig S, Shield A. Eccentric hamstring strength during the nordic hamstring exercises is a risk factor for hamstring strain injury in elite Australian football: a prospective cohort study. Br J Sports Med. 2014;48(7):647–8; doi: 10.1136/bjsports-2014-093494.232.
[82] Chebbi S, Chamari K, Van Dyk N, Gabbett T, Tabben M. Hamstring injury prevention for elite soccer players: a real-world prevention program showing the effect of players' compliance on the outcome. J Strength Cond Res. 2022;36(5):1383–8; doi: 10.1519/JSC.0000000000003505.
[83] Petersen J, Thorborg K, Nielsen MB, Budtz-Jørgensen E, Hölmich P. Preventive effect of eccentric training on acute hamstring injuries in men's soccer: a cluster-randomized controlled trial. Am J Sports Med. 2011;39(11):2296–303; doi: 10.1177/0363546511419277.
[84] Giakoumis M, Pollock N, Mias E, McAleer S, Kelly S, Brown F, Wootten M, Macdonald B. Ec-

centric hamstring strength in elite track and field athletes on the British Athletics world class performance program. Phys Ther Sport. 2020;43:217–23; doi: 10.1016/j.ptsp.2020.03.008.

[85] van der Horst N, van de Hoef S, Reurink G, Huisstede B, Backx F. Return to play after hamstring injuries: a qualitative systematic review of definitions and criteria. Sports Med. 2016;46(6):899–912; doi: 10.1007/s40279-015-0468-7.

[86] Alexander J, Carling C, Rhodes D. Utilisation of performance markers to establish the effectiveness of cold-water immersion as a recovery modality in elite football. Biol Sport. 2022;39(1):19–29; doi: 10.5114/biolsport.2021.103570.

[87] Buckthorpe M, Wright S, Bruce-Low S, Nanni G, Sturdy T, Gross AS, Bowen L, Styles B, Della Villa S, Davison M, Gimpel M. Recommendations for hamstring injury prevention in elite football: translating research into practice. Br J Sports Med. 2019;53(7):449–56; doi: 10.1136/bjsports-2018-099616.

[88] Rhodes D. The Temporal Pattern of Recovery of Eccentric Hamstring Strength and Dynamic Stability in Elite Footballers. 2017. Edge Hill University. Available from: https://research.edgehill.ac.uk/ws/portalfiles/portal/20512569/Rhodes_David_Final_Thesis_2017.11.06_.pdf (accessed November 06, 2017).

[89] Alexander J, Jeffery J, Rhodes D. Recovery profiles of eccentric hamstring strength in response to cooling and compression. J Bodyw Mov Ther. 2021;27:9–15; doi: 10.1016/j.jbmt.2021.03.010.

[90] Barnes C, Archer DT, Hogg B, Bush M, Bradley PS. The evolution of physical and technical performance parameters in the English Premier League. Int J Sports Med. 2014;35(13):1095–100; doi: 10.1055/s-0034-1375695.

[91] Haugen T, Tønnessen E, Hisdal J, Seiler S. The role and development of sprinting speed in soccer. Int J Sports Physiol Perform. 2014;9(3):432–41; doi: 10.1123/ijspp.2013-0121.

[92] Wallace JL, Norton KI. Evolution of World Cup soccer final games 1966–2010: game structure, speed and play patterns. J Sci Med Sport. 2014; 17(2):223–8; doi: 10.1016/j.jsams.2013.03.016.

[93] Faude O, Koch T, Meyer T. Straight sprinting is the most frequent action in goal situations in professional football. J Sports Sci. 2012;30(7):625–31; doi: 10.1080/02640414.2012.665940.

[94] Külah E, Alemdar H. Quantifying the value of sprints in elite football using spatial cohesive networks. Chaos Solitons Fractals. 2020;139:110306; doi: 10.1016/j.chaos.2020.110306.