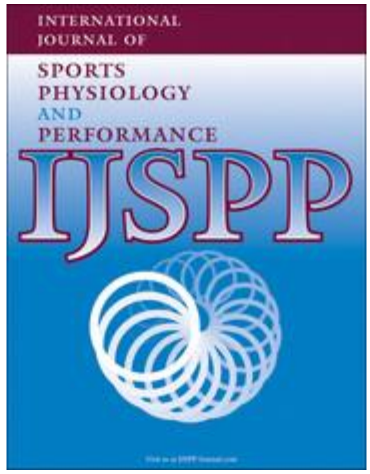


***In press***

***Title:*** **The effect of body mass on eccentric knee flexor strength assessed with an instrumented Nordic hamstring device (Nordbord) in football players.**

***Submission type:*** **Original communication**

***Authors:*** *M. Buchheit.*[1], *Y. Cholley* [1], *M. Nagel*[2], *N. Poulos*[2]

[1] Performance Department, Paris Saint-Germain Football Club, Saint-Germain-en-Laye, France
[2] Adelaide Crows Football Club, Adelaide, Australia

***Running Head:*** Eccentric knee flexor strength and body mass

***Contact details:***
Martin Buchheit
Performance Department, Paris Saint-Germain Football Club,
4a avenue du président Kennedy
78100 Saint-Germain-en-Laye, France
Tel.: +33 1 61 07 10 77
E-mail: mbuchheit@psg.fr

***Abstract word count:*** **248**

***Text-only word count:*** **2837**

***Number of Tables:*** **1**

***Number of Figures:*** **3**

***Disclosures:*** nothing to disclose

## 1. Abstract

*Purpose.* The aims of the present study were to 1) examine the effect of body mass (BM) on eccentric knee flexor strength using the Nordbord, and 2) offer simple guidelines to control for effect of BM on knee flexors strength.

*Methods.* Data from 81 soccer players (U17, U19, U21, senior 4$^{th}$ French division and professionals) and 41 Australian Football League (AFL) players were used for analysis. They all performed one set of three maximal repetitions of the bilateral Nordic hamstring exercise, with the greatest strength measure used for analysis. The main regression equation obtained from the overall sample was used to predict eccentric knee flexor strength from a given BM (moderate TEE, 22%). Individual deviations from the BM-predicted score were used as a BM-free index of eccentric knee flexor strength.

*Results.* There was a large (r = 0.55, 90% confidence limits: 0.42;0.64) correlation between eccentric knee flexor strength and BM. Heavier and older players (professionals, 4$^{th}$ French division and AFL) outperformed their lighter and younger (U17-U21) counterparts, with the soccer professionals presenting the highest absolute strength. Professional soccer players were the only ones to show strength values likely slightly greater than those expected for their BM.

*Conclusions.* Eccentric knee flexor strength, as assessed with the Nordbord, is largely BM-dependent. To control for this effect, practitioners may compare actual test performances with the expected strength for a given BM, using the following predictive equation: eccentric strength (N) = 4 x BM (kg) + 26.1. Professional soccer players with specific knee flexors training history and enhanced neuromuscular performance may show higher than expected values.

**Keywords:** hamstring strength; injuries; Australian Football League; soccer; association football.

## 2. Introduction

Hamstring muscle injuries are the most prevalent injury type in most football codes (e.g., soccer, rugby union, Australian Football League, AFL), and are notorious for their high recurrence rate.[1] While still a matter of debate, it is believed that a large proportion of injuries occur during the terminal swing phase of high-speed running, when the hamstrings (i.e., knee flexors) are required to perform a forceful eccentric contraction.[2] While hamstring strain is clearly multifactorial (e.g., muscle strength imbalance, poor flexibility, muscle fatigue, inadequate warm-up, previous strain/inadequate rehabilitation),[1] lower levels of eccentric hamstring strength have been suggested to increase the risk of future hamstring injuries,[3] indicating the potential significance of eccentric strength (training) for hamstring strain avoidance.[4]

When it comes to the assessment of players' eccentric hamstring strength, isokinetic dynamometry is generally considered as the gold standard measure.[5] However, the high cost of the device and its lack of portability in the field are important limitations to its widespread use. Handheld dynamometers have been suggested as a valid field-based alternative,[6] but their use still requires qualified and highly skilled operators. To overcome these latter limitations, Opar et al.[7] have recently developed a novel field testing device for the assessment of hamstring eccentric strength called the Nordbord[7], based on the commonly employed Nordic hamstring exercise. The Nordbord allows, in ambulatory conditions and within less than 2 minutes per player, the assessment of maximal eccentric knee flexor strength (i.e., force in Newtons captured by load cells used as a measure of strength) and between-limb imbalances. The device is with no surprise receiving an exponentially increasing interest in the field today, and some interesting applications have recently been published. For example, Opar et al. have shown that there may exist an eccentric knee flexor strength threshold (i.e., 265 N) in AFL players, below which injury risk may be substantially increased.[8]

While this device has been shown to provide reliable measures of eccentric knee flexor strength (CV = ~8%[7]), the possible influence of body mass (BM) on the measured eccentric strength has not yet been examined. In fact, for most neuromuscular-related types of measures, including hamstring strength,[9] muscle mass is generally beneficial for performance.[10] Understanding the effect of BM on eccentric knee flexor strength when using the Nordbord has important implications when comparing players differing in body size and/or when monitoring individual players over long periods of time where changes in BM can occur. Additionally, because of the upper body inclination when leaning forward during the Nordic exercise (Figure 1), heavier and/or taller players with a longer lower-leg lever (distance from knee joint axis of rotation to the ankle strap) may apply higher levels of force to the dynamometers, which may, in turn, be interpreted as a greater eccentric knee flexor strength, independent (at least partially) of players' true strength. If BM was to substantially affect the Norbord measures, practical guidelines may be required to correctly interpret potential injury risk in players differing in BM (i.e., the 256 N threshold[8] may be easier to reach for heavier players, independent of their actual eccentric strength). While knee flexor strength per unit of BM (i.e., N/kg) has been used to account for differences in BM,[8] whether such a normalization is completely effective to remove the effect of BM is still unknown. For example, when using allometric scaling, the normalization of lower limb muscle strength is often optimal when using fractions (e.g., $N/kg^{0.67}$)[11] or multiples (e.g., $N/kg^{1.15}$)[12] of BM.

The aims of the present study were therefore to: 1) examine the effect of BM on eccentric knee flexor strength assessed with the Nordbord in football players differing in age and playing standards, and 2) offer simple guidelines to control for the possible effect of BM on eccentric knee flexor strength.

## 3. Methods

*Participants and study overview.*

Data were collected in six different groups of football players: 21 under 17 (U17); 20 U19 and 10 U21 soccer players representative of an elite French academy competing in the highest youth leagues; 16 senior soccer players competing in the 4th French division; 14 professional players competing in the first French and Champions Leagues; and finally, 41 professional AFL players. All data were collected in-season, at least 4 days after players' latest match. Players were all familiar with the Nordic exercise, which was included in their weekly lower-limb strength program at all their respective clubs. These data arose as a condition of player monitoring in which player activities are routinely measured over the course of the competitive season;[13] therefore, ethics committee clearance was not required. The study conformed nevertheless to the recommendations of the Declaration of Helsinki. Data from players with an injury sustained within the six-month period preceding the study were not included.

***Methodology.***

*Anthropometry.* BM (digital balance, ± 0.1 kg) and the sum of 7 skinfolds (bicep, tricep, subscapular, supraspinale, abdominal, mid-thigh, calf, as per ISAK recommendations) were assessed within two weeks of knee flexor strength testing. Percentage of body fat was calculated according to the methods of Withers et al.[14]

*Eccentric knee flexor strength testing.* The device used to determine eccentric knee flexor strength during the Nordic hamstring exercise, and its reliability, have been described previously.[7] Briefly, players knelt on a padded board, with the ankles secured immediately superior to the lateral malleolus by individual ankle braces which were attached to custom made uniaxial load cells (Delphi Force Measurement, Gold Coast, Australia) with wireless data acquisition capabilities (Mantracourt, Devon, UK) (Figure 1). Following a standardised warm-up (5 min cycling at submaximal intensity, a combination of skipping, high-knees and butt-kicking drills, 10 forward lounges per leg, 10 weight-free deep squats, 30 s of dynamic stretching per leg and 2 Nordic hamstring movements with low resistance), participants performed one set of three maximal repetitions of the bilateral Nordic hamstring exercises. Instructions to players were to gradually lean forward at the slowest possible speed while maximally resisting this movement with both limbs while keeping the trunk and hips held in a neutral position throughout, and the hands held across the chest. Participants were loudly exhorted to provide maximal effort throughout each repetition. A trial was deemed acceptable when the force output reached a distinct peak (indicative of maximal eccentric strength, Figure 2), followed by a rapid decline in force which occurred when the athlete was no longer able to resist the effects of gravity acting on the segment above the knee joint.[7] As between-leg differences were behind the scope of the present study, the average strength of left and right legs was used for analysis.[15]

*Statistical analyses.* Data in the text and figures are presented as means with standard deviations (SD) and 90% confidence limits/intervals (CL/CI). All data were first log-transformed to reduce bias arising from non-uniformity error. Linear regressions were used to examine the relationship between eccentric knee flexor strength and BM, with %BF used as a covariate. The typical error of the estimate (TEE) for the eccentric knee flexor strength vs. BM regression was also calculated and expressed in Newton (N), % and standardised units. The following criteria were adopted to interpret the magnitude of the correlation (r, 90% CI): ≤0.1, trivial; >0.1-0.3, small; >0.3-0.5, moderate; >0.5-0.7, large; >0.7-0.9, very large; and >0.9-1.0, almost perfect. If the 90% CI overlapped small positive and negative values, the magnitude was deemed unclear; otherwise that magnitude was deemed to be the observed magnitude.[16]

With respect to the allometric scaling procedure, knee flexor absolute strength (N) was used as the dependent variable, and BM (kg) as the independent variable. The following steps outline the procedures used to construct the model.[11,17] First, normality of the dependent variables was assessed in the entire cohort. Second, a log-linear regression analysis was performed on the independent and dependent variables. The slope of the regression line (90% CL) was used as the allometric scaling exponent. Third, distribution of residuals and the assumption of homoscedasticity were tested by the Anderson-Darling normality test and visual inspection of the residuals. The residual errors should demonstrate a constant variance (homoscedasticity) and a normal distribution, indicating that the model fits all individuals across the entire range. Lastly, independence of the power ratio (i.e., allometrically-scaled strength) and independent variable (i.e., BM) was assessed. For an allometric model to be deemed appropriate there should be no significant correlation between the allometrically-scaled strength measures and the independent variable. The equation characterising the relationship between eccentric knee flexor strength and BM was used to calculate the expected strength for a given BM for each individual. Individual differences in strength from the expected values (i.e., relative strength) were compared to the smallest worthwhile difference (SWD), which was set as 0.2 of the TEE.[18] For individuals, longitudinal changes or difference vs. group mean are generally considered as substantial when the probabilities are ≥75%, which occurs when the difference is greater than the sum of the smallest worthwhile difference (SWD) and the typical error of measurement[18] (TE, from reliability studies, = ~8%[7]). Between-group differences in anthropometric measures, absolute and relative eccentric strength were examined using standardised differences, based on Cohen's effect size principle. Probabilities were used to make a qualitative probabilistic mechanistic inference about the true differences between the groups. The scale was as follows: 25−75%, possible; 75−95%, likely; 95−99%, very likely; >99%, almost certain.[16]

## 4. Results

The force trace of a representative professional players during three repeated Nordic hamstring exercises on the Nordbor is shown in Figure 2. For pooled data (n = 122), there was a large correlation between eccentric knee flexor strength and BM (Figure 3, r = 0.55, 90% CL: 0.42;0.64). Controlling for %BF did not affect the magnitude of the correlation (partial r for eccentric knee flexor strength and BM = 0.54, 0.42;0.64). The TEE for eccentric knee flexor strength vs. BM was rated as moderate, i.e., standardised TEE = 0.84 (90% CL: 0.76;0.94), 65 N (59;73), or 22 % (19;42). The linear regression equation describing the relationship between eccentric knee flexor strength and BM was: eccentric strength (N) = 4 x BM (kg) + 26.1.

The different parameters derived from the allometric scaling within each group are shown in Table 1. There was unclear (U21 and 4th Div) to large (U17, U19 and Pro Soccer) correlations between eccentric knee flexor strength and BM. The exponent k was clearly group-dependent (range: 0.57-1.51), with an average value of 0.89 (0.85;0.92) when all players were pooled together.

Players' absolute eccentric knee flexor strength values are presented in Table 1. Figure 4 shows that the average absolute eccentric strength observed in the present study (all players pooled together, and in the Pro Soccer and AFL players specifically) was slightly greater than those previously published.

There was a trend for the heavier and older players (4th Division Soccer, Pro Soccer and AFL) to perform better than their lighter and younger (U17-U21) counterparts, with the Pro soccer team presenting the highest absolute strength. While all the other teams showed values within their BM-expected ranges (within the SWD, Figure 4), Pro Soccer players showed strength values likely slightly (20%) greater than their BM-expected values (Figure 5).

## 5. Discussion

In this study we quantified the likely effect of BM on eccentric knee flexor strength when using the Nordbord device. We also reported some eccentric knee flexor strength values in various football players differing in age and playing standards. The main results were as follows: 1) when all players were pooled together, there was a large correlation between eccentric knee flexor strength and BM, 2) the allometric exponent describing the relationship between eccentric knee flexor strength and BM was population-dependent but in overall, slightly but substantially lower than 1, and 3) the heavier and older players (4$^{th}$ Division Soccer, Pro Soccer and AFL) performed better than their lighter and younger (U17-U21) counterparts, with the professional soccer players outperforming the heavier AFL players.

Confirming our initial hypothesis, we observed unclear-to-large correlations between eccentric knee flexor strength and BM (Table 1). While correlations don't imply causality, the likely effect of BM on eccentric knee flexor strength may be linked to the fact that when leaning forward during the Nordic exercise, players' BM may affect the force applied to the dynamometers, at least partially independent of players' true strength. For instance, the data plotted in Figure 3 suggest that eccentric knee flexor strength is likely to increase by 4 N per increase in 1 kg of BM (eccentric strength (N) = 4 x BM (kg) + 26.1). One of the consequences of the present findings is that the use of a unique absolute eccentric strength threshold value (i.e., 265 N)[8] to identify players with increased hamstring injury risk, without taking their own BM into consideration, may be questionable. The present data (Table 1) showed also that the allometric exponent that could be used to normalise eccentric knee flexor strength on BM is likely lower than 1, which suggests that simply dividing eccentric strength by units of BM (i.e., N/kg)[8] may not be optimal either. The various allometric scaling parameters detailed in Table 1 confirm, however, that the relationship between eccentric knee flexor strength and BM is complex, and may be specific to the group of players considered.[11] This athlete and performance specificity is unfortunately a clear limitation in practice, when practitioners are seeking to standardize their own test measures (e.g. calculation of the allometric exponents for their specific data set, normalisation process, changes in units that occur with scaling).[17]

To overcome these latter limitations and offer a simple way to control for the effect of BM on eccentric knee flexor strength when using the Nordbord, practitioners could use the provided regression equation (Figure 3) to estimate a player's expected strength based on his own BM, and compare it with his actual (measured) performance. As shown in Figure 3, while player B (106 kg) demonstrates one of the highest level of absolute strength (495 N), in comparison with his BM-expected strength (451 N), his relative strength (+10%) is actually lower than that of player A (75kg, 429 – 326 N = +32%). When interpreting these individual differences with respect to the different magnitude thresholds (Figure 3), player A shows likely largely greater relative strength than his BM-expected value (310 N), while player C, moderately lower strength (239 N). In contrast, player B shows values within the range of his expected values (i.e., within the sum of the smallest worthwhile difference and the typical error of the measure, ± SWD + TE). It is worth noting that in the present case, when considering a unique eccentric strength measure (1 visit), and knowing that the minimum difference that can be assessed with a probability of at least 75% = SWD + TE = 13 N (4%) + 27 N (8%[7]) = 40 N (12%), only moderate differences vs. BM-expected strength could be assessed at the individual level (since a moderate standardised difference based on Cohen's effects is 0.6; 0.6 x TEE = 40 N or 13%).

When looking at between-group differences in eccentric knee flexor strength, there was a trend for the heavier and older players (4$^{th}$ Division Soccer, Pro Soccer and AFL) to perform better than their lighter and younger (U17-U21) counterparts, with the professional soccer team presenting the highest absolute strength

(411 ± 65 N, Table 1). Comparison with the literature is impossible for soccer players, but the 371 ± 77 N observed in our AFL players (86 kg) is very similar to the 372 N (BM not provided)[7] or slightly greater than the 320-330 (81-88 kg)[8,15] N reported previously in similar populations (Figure 4). The reasons for the likely moderately greater absolute eccentric knee flexor strength of the professional soccer players compared with the other soccer players is not surprising and likely related to their specific training history on that muscle group at the club.[19,20] In fact, high-standard soccer players are often reported to outperform their lower-standard counterparts in strength-oriented tests, including eccentric knee flexor strength.[21] Interestingly, the professional soccer players were the only ones to show relative strength values likely slightly greater (20%) than those expected for their own BM (Figure 4 and 5). In fact, while being likely moderately lighter than their AFL counterparts (-7 kg), they showed likely moderately greater strength values (+40 N, Table 1). The reason for the lower performance of the AFL players compared with their professional soccer counterparts deserves further investigation, but differences in match demands[22,23] and training methods[19,20] within each club may have to be considered. Further analysis of muscle characteristics (muscles size, fiber types, neural activation) and detailed training history may also help to shed light on this latter observation.

## 6. Practical applications

To compare players differing in BM, or when monitoring individual players over long periods of time when changes in BM may occur, practitioners can use the provided equation (eccentric strength (N) = 4 x BM (kg) + 26.1) to estimate a player's expected strength based on their own BM, and compare it with their actual (measured) performance. When using a single test measure in individual players, values deviating from the body-mass expected values by at least 40 N (12%) may be considered as substantially greater or lower. In players diagnosed as weaker than their BM-expected performance, individualized training interventions aimed at increasing eccentric knee flexor strength could be implemented.[19,20]

## 7. Conclusions

Eccentric knee flexor strength, as assessed with the Nordbord device is largely BM -dependent. To control for this effect, practitioners may compare actual test performances with the expected strength for a given BM, using the following predictive equation: eccentric strength (N) = 4 x BM (kg) + 26.1.

## 8. Acknowledgements

The authors thank the coaches, physiotherapists and supporting staff of the different teams for facilitating data collection.

## 9. References


1. Opar DA, Williams MD, Shield AJ. Hamstring Strain Injuries: Factors that Lead to Injury and Re-Injury. *Sports Med.* Mar 1 2012;42(3):209-226.
2. Guex K, Millet GP. Conceptual framework for strengthening exercises to prevent hamstring strains. *Sports Med.* Dec 2013;43(12):1207-1215.
3. Sugiura Y, Saito T, Sakuraba K, Sakuma K, Suzuki E. Strength deficits identified with concentric action of the hip extensors and eccentric action of the hamstrings predispose to hamstring injury in elite sprinters. *The Journal of orthopaedic and sports physical therapy.* Aug 2008;38(8):457-464.
4. Petersen J, Thorborg K, Nielsen MB, Budtz-Jorgensen E, Holmich P. Preventive effect of eccentric training on acute hamstring injuries in men's soccer: a cluster-randomized controlled trial. *Am J Sports Med.* Nov 2011;39(11):2296-2303.
5. Aagaard P, Simonsen EB, Magnusson SP, Larsson B, Dyhre-Poulsen P. A new concept for isokinetic hamstring: quadriceps muscle strength ratio. *Am J Sports Med.* Mar-Apr 1998;26(2):231-237.
6. Whiteley R, Jacobsen P, Prior S, Skazalski C, Otten R, Johnson A. Correlation of isokinetic and novel hand-held dynamometry measures of knee flexion and extension strength testing. *J Sci Med Sport.* Sep 2012;15(5):444-450.
7. 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. *The Journal of orthopaedic and sports physical therapy.* Sep 2013;43(9):636-640.
8. 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.* Apr 2015;47(4):857-865.
9. Zakas A, Mandroukas K, Vamvakoudis E, Christoulas K, Aggelopoulou N. Peak torque of quadriceps and hamstring muscles in basketball and soccer players of different divisions. *J Sports Med Phys Fitness.* Sep 1995;35(3):199-205.
10. Nedeljkovic A, Mirkov DM, Bozic P, Jaric S. Tests of muscle power output: the role of body size. *Int J Sports Med.* Feb 2009;30(2):100-106.
11. Jaric S, Mirkov D, Markovic G. Normalizing physical performance tests for body size: a proposal for standardization. *J Strength Cond Res.* May 2005;19(2):467-474.
12. Carvalho HM, Coelho-e-Silva M, Valente-dos-Santos J, Goncalves RS, Philippaerts R, Malina R. Scaling lower-limb isokinetic strength for biological maturation and body size in adolescent basketball players. *Eur J Appl Physiol.* Aug 2012;112(8):2881-2889.
13. Winter EM, Maughan RJ. Requirements for ethics approvals. *J Sports Sci.* Aug 2009;27(10):985.
14. Withers RT, Craig NP, Bourdon PC, Norton KI. Relative body fat and anthropometric prediction of body density of male athletes. *Eur J Appl Physiol Occup Physiol.* 1987;56(2):191-200.
15. 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 preseason training in elite Australian footballers. *Am J Sports Med.* Feb 2015;43(2):377-384.
16. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* Jan 2009;41(1):3-13.
17. Buchheit M, Mendez-Villanueva A, Jullien H, et al. Locomotor Performance in Highly-trained Young Soccer Players: Does Body Size Always Matter? . *Int J Sports Med.* 2013: Nov 7. [Epub ahead of print].
18. Hopkins WG. How to Interpret Changes in an Athletic Performance Test. *Sportscience.* 2004; 8:1-7.
19. Gur H, Akova B, Punduk Z, Kucukoglu S. Effects of age on the reciprocal peak torque ratios during knee muscle contractions in elite soccer players. *Scand J Med Sci Sports.* Apr 1999;9(2):81-87.
20. Mendiguchia J, Martinez-Ruiz E, Morin JB, et al. Effects of hamstring-emphasized neuromuscular training on strength and sprinting mechanics in football players. *Scand J Med Sci Sports.* Dec 30 2014.

21. Cometti G, Maffiuletti NA, Pousson M, Chatard JC, Maffulli N. Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. *Int J Sports Med.* Jan 2001;22(1):45-51.
22. Gray AJ, Jenkins DG. Match analysis and the physiological demands of Australian football. *Sports Med.* Apr 1 2010;40(4):347-360.
23. 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.* Dec 2014;35(13):1095-1100.

**Figure 1.** Under 17 player performing the Nordic hamstring exercise on the Nordbord.

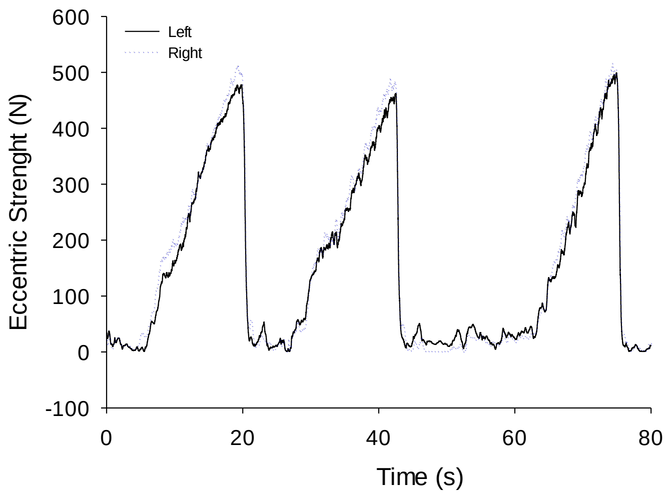


**Figure 2.** Force trace during three consecutive Nordic hamstring exercises on the Nordbord in a representative professional soccer player.

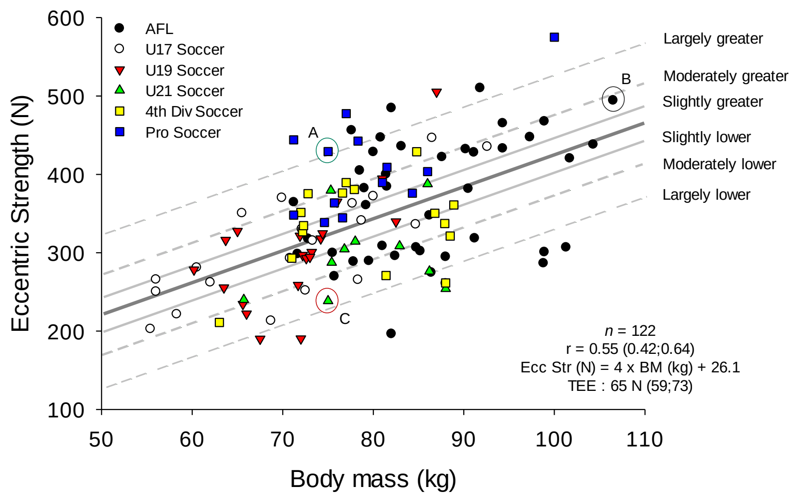


**Figure 3.** Relationship (r with 90% confidence intervals) between eccentric knee flexor strength and body mass (BM) in the six teams. TEE: typical error of the estimate, with 90% confidence intervals. The different lines represent threshold for slightly, moderately and largely lower/greater values than BM-expected strength, based on Cohen's effect size principle. For individuals, difference vs. group mean are generally considered as substantial when the probabilities are ≥75%, which occurs when the difference is greater than the sum of the smallest worthwhile difference (SWD, = TEE/5) and the typical error of measurement (TE, from reliability studies).

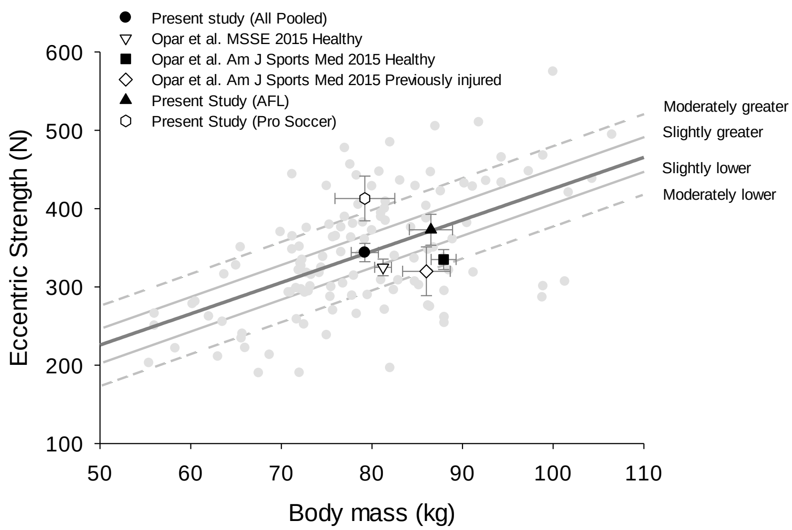


**Figure 4.** Comparison of the present data (all payers pooled together and a selection of two teams, i.e., Australian Football League players, AFL and professional soccer players, Pro Soccer) with previously published values in AFL players. The light-grey dots represent individual values from the present study (Figure 1). Opar et al. MSSE 2015[8] and Opar et al. Am J Sports Med 2015.[15] Data are mean with 90% confidence intervals. The different lines represent threshold for slightly, moderately and largely lower/greater values than BM-expected strength, based on Cohen's effect size principle.

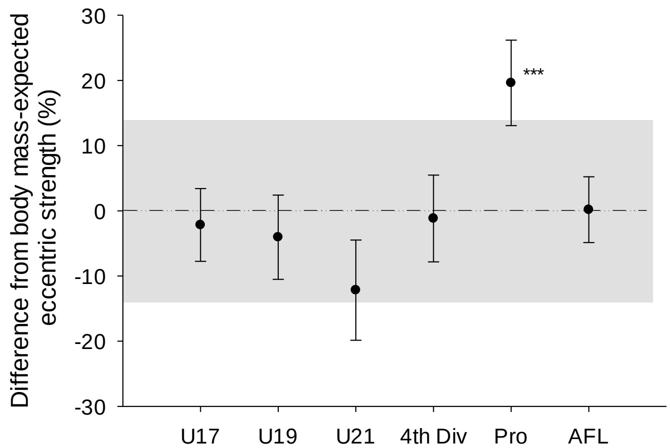


**Figure 5.** Difference in measured vs. body mass (BM)-expected eccentric knee flexor strength in the six teams. The symbols stand for a likely small difference vs. BM-expected knee flexors strength. 4th Div: 4th French division soccer, Pro: professional soccer 1st French League, AFL: Australian Football League. The grey area represents the smallest worthwhile difference in eccentric knee flexor strength (see method).

**Table 1.** Players' characteristics, absolute and relative eccentric knee flexor strength as measured with the Nordbord device.

| | n | Age (yr) | Body mass (kg) | Body Fat (%) | Two-leg average strength (N) | Two-leg average BM-free expected strength (N) | Allometry (exponent k and correlation coefficient r with 90% confidence intervals) |
|---|---|---|---|---|---|---|---|
| U17 Soccer | 21 | 16.2 ± 0.6 | 71.8 ± 11.2 [aabbccddd] | 11.0 ± 2.7 [bbcccddd] | 306 ± 68 [bcccdd] | 312 ± 45 [aabbccddd] | k = 0.88 (0.76;0.94)<br>r = 0.66 (0.38;0.83) |
| U19 Soccer | 20 | 18.0 ± 0.6 | 71.7 ± 6.8 [aabbccddd] | 11.2 ± 1.5 [bbcccddd] | 301 ± 72 [bcccdd] | 312 ± 27 [aabbccddd] | k = 1.51 (1.16;1.75)<br>r = 0.62 (0.31;0.83) |
| U 21 Soccer | 10 | 19.6 ± 0.6 | 78.9 ± 6.9 [dd] | 11.1 ± 1.5 [bbcccddd] | 299 ± 52 [ddcccdd] | 341 ± 27 [dd] | k = 0.57 (0.03;0.85)<br>r = 0.30 (-0.30;0;73) |
| $4^{th}$ Division Soccer | 16 | 25.2 ± 7.1 | 78.8 ± 8.0 [dd] | 9.3 ± 2.9 [ccddd] | 336 ± 55 [cccd] | 340 ± 32 [dd] | k = 0.57 (0.19;0.80)<br>r = 0.33 (-0;11;0.66) |
| Pro Soccer | 14 | 24.6 ± 5.3 | 79.1 ± 7.5 [dd] | 7.5 ± 0.9 [d] | 411 ± 65 [dd] | 343 ± 30 [dd] | k = 0.95 (0.87;0.98)<br>r = 0.58 (0.16;0.82) |
| AFL | 41 | 24.3 ± 4.2 | 86.4 ± 9.3 | 7.2 ± 0.6 | 371 ± 77 | 371 ± 37 | k = 0.65 (0.47;0.78)<br>r = 0.32 (0.06;0.54) |
| All pooled | 122 | 21.6 ± 6.5 | 79.0 ± 10.5 | 9.1 ± 2.6 | 342 ± 78 | 342 ± 42 | k = 0.89 (0.85;0.92)<br>r = 0.54 (0.42;0.64) |

AFL: Australian Football League. The letters refer to substantial differences vs. U21 (a), $4^{th}$ Division Soccer (b), Pro Soccer (c) and AFL (d), with the number of letters standing for small (1), moderate (2) and large (3) magnitudes. All substantial differences were at least likely (≥75%).