Title

Is pre-season eccentric strength testing during the Nordic hamstring exercise associated with future hamstring strain injury? A systematic review and meta-analysis

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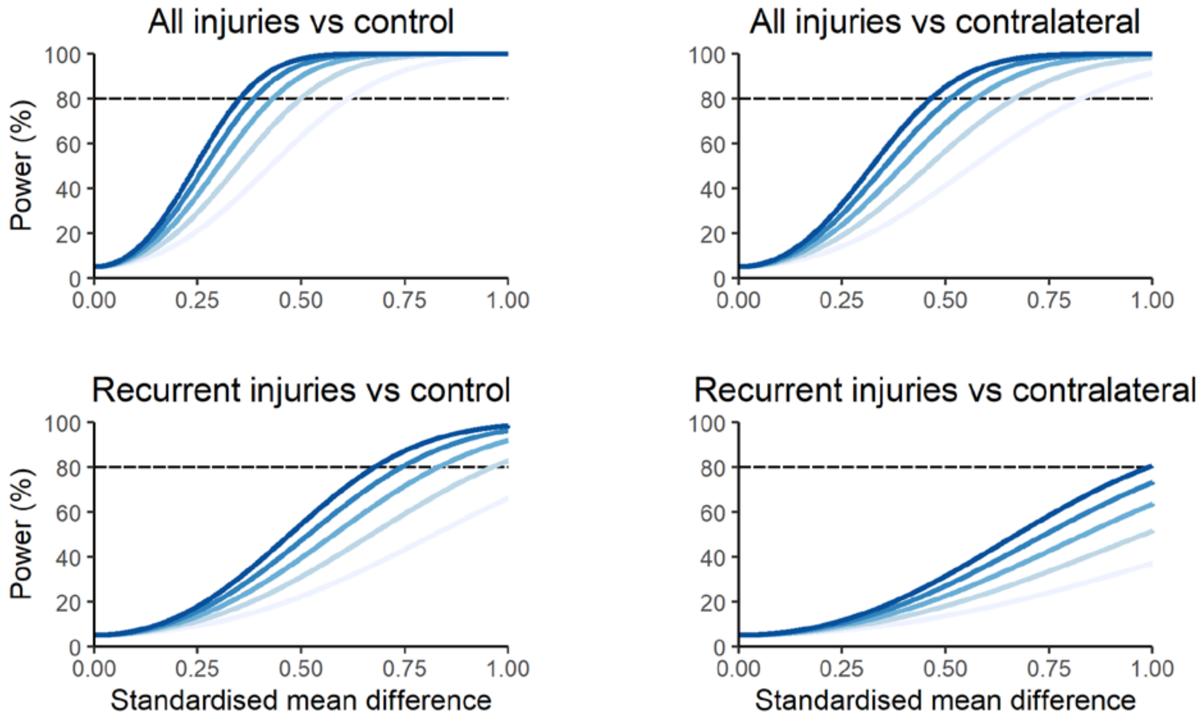
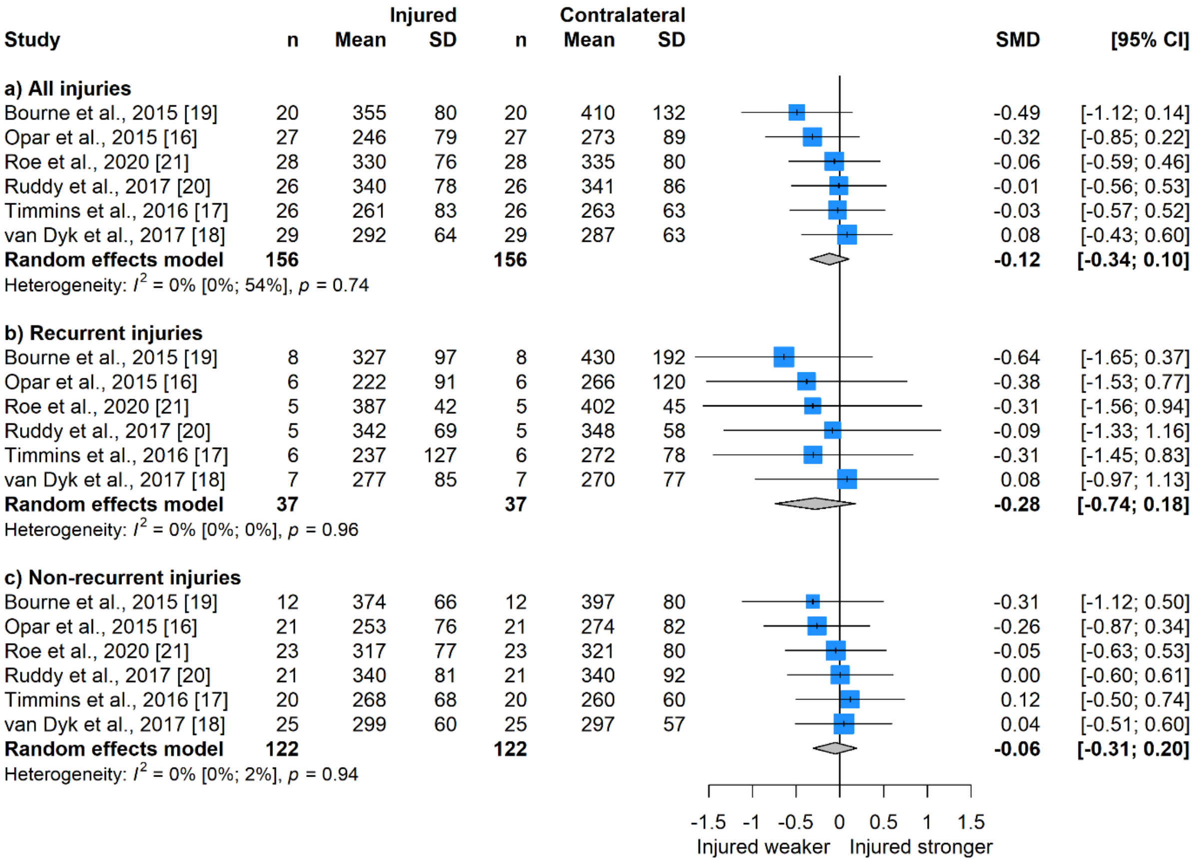
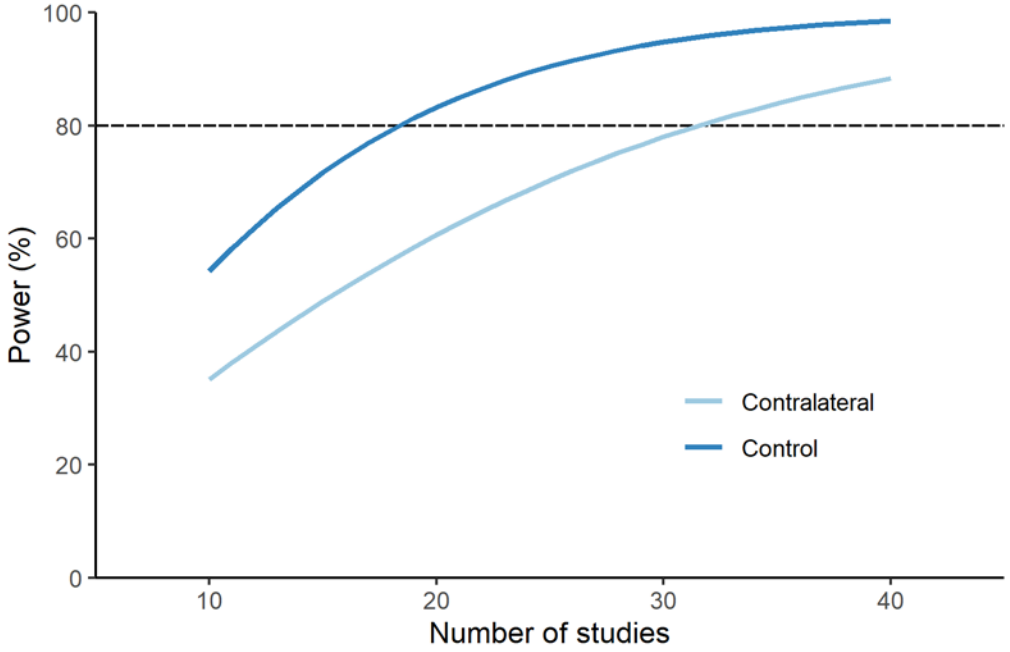


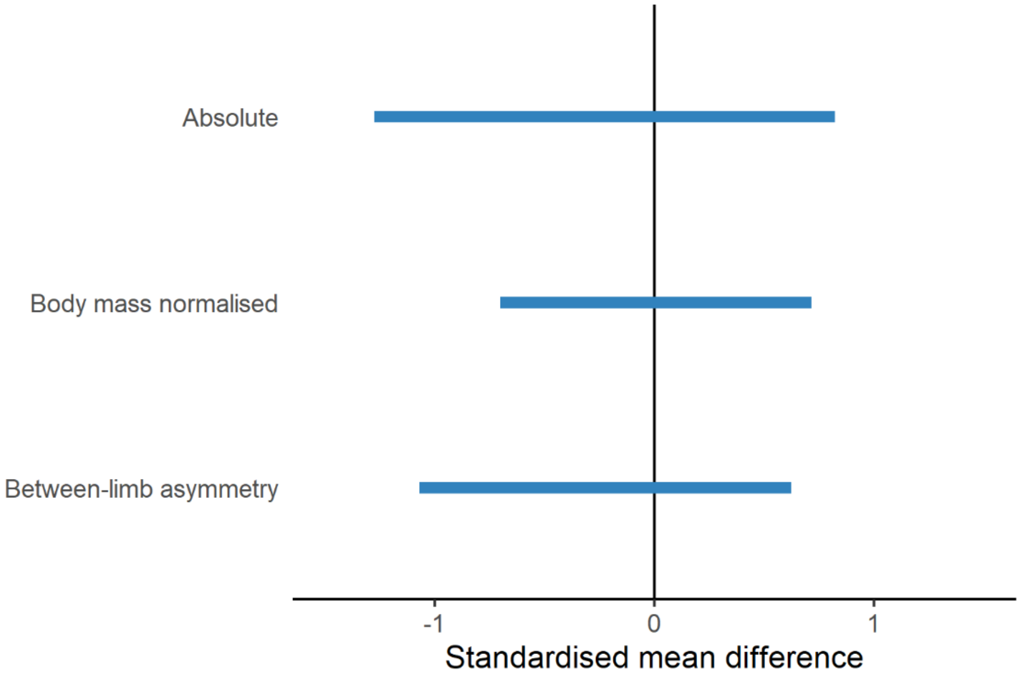
Supplementary Figure S1. Power analysis for meta-analysis assessing the relationship between eccentric knee flexor strength quantified during performance of the Nordic hamstring exercise (NHE) and risk of hamstring strain injury. Power curves are shown for 2 (lightest coloured line) to 6 studies (darkest coloured line). For these calculations, we estimated the sample of each study as n = 25 injured/contralateral legs and n = 150 uninjured participants. These numbers were conservatively estimated based on the seminal paper by Opar et al. [16]. For recurrent injury calculations, we estimated n = 6 injured/contralateral injuries based on Opar et al. [16]. Due to the conflicting nature of the reported results from the ensuing work [17-21], high heterogeneity was assumed for these calculations.



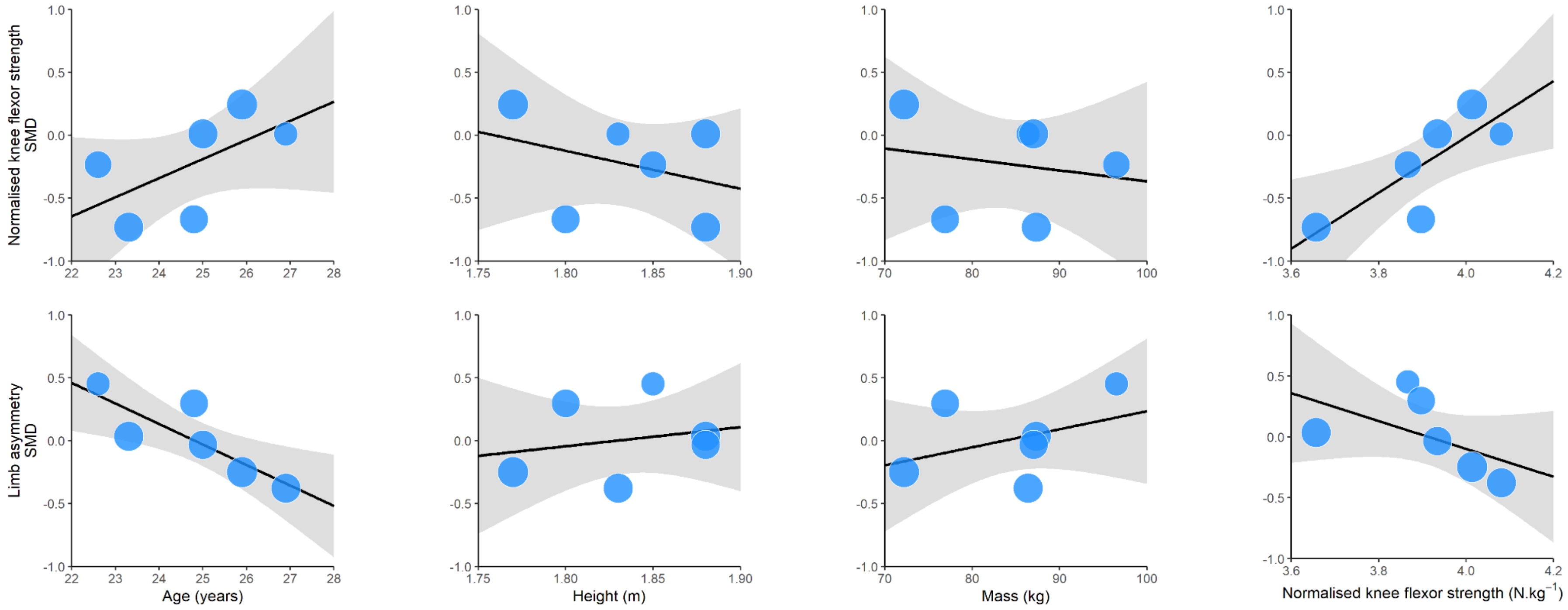
Supplementary Figure S2. Standardised mean differences (SMD) of absolute eccentric knee flexor strength quantified during performance of the Nordic hamstring exercise strength (N) for the hamstring strain injured limbs compared to the uninjured contralateral limbs. Data is sub-grouped for a) all injuries, b) recurrent injuries, c) non-recurrent injuries. Recurrent injury classification was achieved through author contact and was defined as athletes that suffered a hamstring strain injury (HSI) in the 12 months prior to test, and then suffered a subsequent HSI in the same leg during the follow-up period. Note that for one study [18], the recurrent and non-recurrent injured-group limbs could only be identified on a player-season level, not an individual participant level (due to participant de-identification). Due to 3 players in this study suffering injuries across both of the assessed seasons, the sum of recurrent and non-recurrent injuries exceeds the total amount of injuries reported in panel a.



Supplementary Figure S3. Power analysis-based prediction of the number of studies needed to detect a small effect size (0.20) for studies assessing the relationship between eccentric knee flexor strength quantified during performance of the Nordic hamstring exercise (NHE) and hamstring strain injury. Power curves are provided for control group comparisons (dark blue, assuming n=25 injured participants and n=150 uninjured participants) and contralateral limb comparisons (light blue, assuming n=25). Study sample sizes were conservatively estimated based on the seminal paper by Opar et al. [16]. Due to the conflicting nature of the reported results from the currently published studies [16-21], high heterogeneity was assumed for these calculations.



Supplementary Figure S4. Prediction intervals for the difference in eccentric knee flexor strength quantified during performance of the Nordic hamstring exercise (NHE) between athletes that went on to suffer a hamstring strain injury (n = 156), and athletes that did not (n = 1160). Absolute, absolute eccentric knee flexor strength (N); Body mass normalised, body mass normalised knee flexor strength ($N.kg^{-1}$); Between-limb asymmetry, difference in absolute knee flexor strength between limbs relative to the stronger limb (%). Note that prediction intervals reflect the variation in effects across different settings, including what effect may be expected in future settings [46].



Supplementary Figure S5. Meta-regression of body mass normalised knee flexor strength quantified during performance of the Nordic hamstring exercise standardised mean difference (SMD) between prospectively hamstring strain injured and uninjured limbs and continuous covariates. Regression analysis was conducted for body mass normalised knee flexor strength ($N.kg^{-1}$, top row) or between-limb asymmetry (%, bottom row). Bubbles, data points representing each study (size of each bubble is inversely proportional to the standard error of the study); black line, regression line of best fit; grey shaded area, 95% confidence interval of regression line.

Supplementary Table S1. Key terms and controlled vocabulary utilised as part of database searches

	Strength descriptor	**Muscle injury type**	**Study descriptor**
Key terms	Hamstring* Eccentric Knee flexor Nordic	Injur* Tear* Strain* Rupture* Pull* Trauma Torn	Prospective Stud* Longitudinal Stud* Cohort Stud* Risk factor*
Controlled vocabulary	Hamstring muscles Eccentric contraction	Wounds and injuries Athletic injuries Sprains and strains Tears and lacerations Rupture Pull Trauma Rupture of organs, tissues, etc.	Prospective Studies Longitudinal Studies Cohort Studies Risk factors

* = Truncation. The Boolean term OR was used within categories, whereas AND was used between categories.

Supplementary Table S2. Quality assessment results using the QUIPS (Quality in Prognostic studies) tool.

Study	Potential risk of bias item						Overall risk of bias
	Study participation	Study attrition	Prognostic factor measurement	Outcome measurement	Study confounding	Statistical analysis and reporting	
Bourne et al., 2015 [19]	Low	Low	Low	Low	Low	Low	Low
Opar et al., 2015 [16]	Low	Low	Low	Low	Low	Low	Low
Roe et al., 2020 [21]	Low	Low	Low	High	High	High	High
Ruddy et al., 2018 [20]	Low	Low	Low	Low	Low	Low	Low
Timmins et al., 2016 [17]	Low	Low	Low	Low	Low	Low	Low
van Dyk et al., 2017 [18]	Low	Low	Low	Low	Low	Low	Low

Supplementary Table S3. Summary of participant characteristics.

Study	n uninjured / injured	Age (years)	Height (m)	Mass (kg)	Sport	Competition level
Bourne et al., 2015 [19]	158 / 20	23 ± 4	1.85 ± 0.07	96.5 ± 13.1	Rugby Union	Elite and sub-elite
Opar et al., 2015 [16]	159 / 27	23 ± 4	1.88 ± 0.07	87.3 ± 8.2	Australian Football	Elite
Roe et al., 2020 [21]	156 / 28	27 ± 3	1.83 ± 0.06	86.4 ± 6.2	Gaelic Football	Elite
Ruddy et al., 2017 [20]	150 / 26	25 ± 3	1.88 ± 0.07	87.0 ± 8.6	Australian Football	Elite
Timmins et al., 2016 [17]	105 / 26	25 ± 5	1.80 ± 0.06	76.9 ± 7.5	Soccer	Elite
van Dyk et al., 2017 [18]	216 / 29	26 ± 5	1.77 ± 0.07	72.2 ± 9.3	Soccer	Elite

Data for age, height and mass are presented as mean ± SD.

Supplementary Table S4. Summary of study methodology.

Study	Protocol (sets x reps)	Data reduction	Time of testing	Follow-up period	Injury diagnosis
Bourne et al., 2015 [19]	1 x 3	Peak force	Within pre-season	~6 months	Imaging or clinical exam
Opar et al., 2015 [16]	1 x 3	Average peak force	Start of pre-season	10 months	MRI confirmed
Roe et al., 2020 [21]	1 x 3	Average peak force	Within pre-season	~3 months	Medical staff
Ruddy et al., 2017 [20]	1 x 3	Average peak force	Start of pre-season	10 months	MRI confirmed
Timmins et al., 2016 [17]	1 x 3	Average peak force	Start of pre-season	10 months	Clinical exam
van Dyk et al., 2017 [18]	1 x 3	Peak & average peak force	Within pre-season	10 months	Imaging or clinical exam

Peak force refers to the single highest peak of the 3 repetitions, whilst average peak force corresponds to the average of the peak of each of the 3 repetitions. Note that where studies reported both peak force and average peak force, the average peak force was utilised in the meta-analysis.

Supplementary Table S5. Meta-regression results for absolute eccentric knee flexor strength quantified during performance of the Nordic hamstring exercise (NHE) and between-limb asymmetry in knee flexor strength effect sizes between the prospectively injured limbs compared to the uninjured control group.

Outcome	Moderator	Q_M	p	R^2
Absolute eccentric knee flexor strength	Age	1.27	0.26	12.05
	Height	0.34	0.56	0.00
	Mass	0.03	0.86	0.00
	Strength	0.48	0.49	0.00
	Sport	0.21	0.98	0.00
Between-limb asymmetry	Age	7.25	<0.01*	100
	Height	0.20	0.65	0.00
	Mass	0.74	0.39	0.00
	Strength	0.25	0.62	0.00
	Sport	4.18	0.24	33.80

Q_M is the model sum of squares. If Q_M is significant (*, $p < 0.05$), then at least one co-efficient in the regression model was significantly different from 0. R^2 represents the total amount of heterogeneity (%) accounted for by the regression model.

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Conflicts of Interest

Dr David Opar is listed as a co-inventor on a patent filed for a field-testing device of eccentric hamstring strength (PCT/AU2012/001041.2012) and is a minority shareholder in Vald Performance Pty Ltd, the company responsible for commercialising the device. The association between measures derived from the device and future hamstring strain injury is directly examined in this manuscript. Dr Opar is also the Chair of the Vald Performance Research Committee, a role that is unpaid. Dr Opar has received funding from Vald Performance for research unrelated to the current manuscript. Dr Opar's brother and brother-in-law are employees of Vald Performance. Dr Opar's brother is a minority shareholder in Vald Performance Pty Ltd.

Ryan Timmins, Fearghal Behan, Jack Hickey, Nicol van Dyk, Kara Price and Nirav Maniar declare that they have no conflicts of interest relevant to the content of this review.

Availability of data and material

Access to data and/or material can be sought via contacting the corresponding author

Code availability

Not applicable

Authorship contributions

DAO, RGT, FPB, JTH, NM conceived the study

DAO, FPB and KP completed study protocol and registration

DAO and RGT completed database searches and extraction

RGT and JTH completed title and abstract screening

FPB and JTH completed full text review

RGT, NvD and FPB completed risk of bias assessment

NM, JTH and NvD completed data extraction

NM and JTH completed data analysis

DAO drafted the Introduction and Methods

NM drafted the Results and Discussion

All authors reviewed, revised and approved the final manuscript