Manuscript title

Calf muscle abilities are related to sprint performance in male Rugby Union players

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Calf muscle and sprint in Rugby Union

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Figures: 1

Supplementary material: Table S1, Figure S1, Figure S2

ABSTRACT

Objectives: To examine the strength of the relationship between plantarflexor power and strength-endurance metrics and 10-m sprint times in male Rugby Union players. A secondary aim was to examine the strength of the relationship within calf muscle metrics. **Design:** Observational cross-sectional correlational. **Setting:** Field-based. **Participants:** Sixteen male Rugby Union players in the National Provincial Championship. **Main Outcome Measures:** Participants completed three single-leg calf muscle tests: bodyweight power, weighted power, and strength-endurance. Data were recorded using the Calf Raise App. Three-to-four days later, average and best 10-m sprint performances were collected using timing lights. **Results:** There were *large* significant correlations between 10-m sprint performances (average and best times) and calf muscle power (weighted) and strength-endurance (total displacement and work) metrics (r = -0.503 to -0.628). There were *large* significant correlations between bodyweight and weighted power, weighted power and strength-endurance (total displacement and work), and most strength-endurance metrics (r = 0.520 to 0.943). **Conclusions:** Our findings emphasise the importance of triceps surae muscle power and strength-endurance for maximal-effort accelerations and sprint performances in Rugby Union. Our data indicate that weighted power and total work from strength-endurance tests are the most useful metrics for further investigation in the context of short sprints and acceleration.

Keywords: Biomechanics; endurance; muscle strength; triceps surae

INTRODUCTION

Rugby Union is a team sport that relies heavily on acceleration, with acceleration being a more important speed-related requirement in game than maximal speed (Pook, 2012). Indeed, *small* to *moderate* correlations exist between 10-m sprint times and key performance indicators, including line breaks, tackle breaks, meters advanced, evasion, and tries scored (Smart, Hopkins, Quarrie, & Gill, 2014). Furthermore, Rugby Union players typically complete numerous repeated sprints (Dubois, et al., 2017) and moderate-to-heavy accelerations (Owen, Venter, du Toit, & Kraak, 2015) within competitive play and training. These repeated sprints and accelerations place large demands on the triceps surae muscles and Achilles tendon (Demangeot, Whiteley, Gremeaux, & Degache, 2023) that cumulate during games and likely contribute to performance reduction and injury incidence in the late stages of games. In fact, the triceps surae (or "calf") muscles and Achilles tendon frequently feature high in injury incidence (Brooks & Kemp, 2011; England Professional Rugby Injury Surveillance Project Steering Group, 2020) and burden (Brooks & Kemp, 2011), being second only to hamstring injuries (England Professional Rugby Injury Surveillance Project Steering Group, 2020).

The plantarflexors are the largest force generators during running, producing combined peak forces totalling approximately 11x body weight (BW) during steady-state running (Dorn, Schache, & Pandy, 2012) and 16x BW during accelerations (Pandy, Lai, Schache, & Lin, 2021). The plantarflexors are the muscles that contribute the most to sprint acceleration, with small increases in ankle power shown to directly influence centre of mass acceleration (Debaere, Delecluse, Aerenhouts, Hagman, & Jonkers, 2015). Of the

lower-extremity joints, the ankle is the one that generates the largest amount of positive work during acceleration (Schache, Lai, Brown, Crossley, & Pandy, 2019). In addition, the plantarflexors and Achilles tendon are important contributors to jumping (Gollhofer, Strojnik, Rapp, & Schweizer, 1992), landing (Baxter, Corrigan, Hullfish, O'Rourke, & Silbernagel, 2021), cutting (Marshall, et al., 2014), and deceleration (Werkhausen, et al., 2017). Altogether, these modelling studies indicate that plantarflexor strength and power may be important qualities for athletic performance, although few studies have directly examined the relationship between plantarflexor function and athletic ability.

The plantarflexors operate very close to their maximal voluntary capacity (MVC) during locomotion, working at 84% and 96% of MVC during steady-state running and top speed sprinting (Kulmala, et al., 2016), respectively. Equally, it is known that high-intensity runs equivalent to that found in Rugby Union lead to fatigue, causing a reduction in plantarflexor work of around 14% (Willer, Allen, Burden, & Folland, 2021). Similar reductions in peak isometric plantarflexor forces (around 11%) are found following sustained running bouts (Murray, Beaven, & Hébert-Losier, 2019). The combination of little reserve capacity and muscular fatigue point to the importance of strength-endurance of the plantarflexors in Rugby Union. Plantarflexor function is critical to both enhancing performance (Möck, Hartmann, Wirth, Rosenkranz, & Mickel, 2018) and mitigating injury risk (Mahieu, Witvrouw, Stevens, Van Tiggelen, & Roget, 2006) in sports, and also during the rehabilitation process of triceps surae muscle-tendon injuries as plantarflexion power and strength-endurance are impaired (McAuliffe, et al., 2019). Previous research has identified *moderate* to *large* correlations between 1-repetition maximum standing calf raise strength and 5-m split times over 30 m in physical education

students (Möck, et al., 2018). It is currently unclear if calf muscle function is associated with athletic performance markers in Rugby Union players, like acceleration or maximal speed abilities. Given that the triceps surae muscles are key for many sport-related activities, including maximal-effort accelerations and sprints, testing calf muscle function can provide information on athletic ability.

We aimed to examine the strength of the relationship between plantarflexor power and strength-endurance metrics and 10-m sprint times in male Rugby Union players. We also conducted a secondary analysis to explore the strength of the association within calf muscle metrics.

MATERIALS AND METHODS

Study design

We used an observational cross-sectional correlational study design to conduct this research. A Human Research Ethics Committee [HREC(Health)2020#11] approved the research protocol, which adhered to the Declaration of Helsinki.

Sample size

Data from a previous study was used to inform our sample size calculations (Möck, et al., 2018). Specifically, this previous study identified a *large* correlation (r = -0.663) between 1-repetition maximum standing calf raise strength and 5 – 10 m split times in physical

education students (Möck, et al., 2018). Our sample size calculations indicated that fifteen participants were required to detect this magnitude of correlation at a 5% significance level with 80% power in a two-sided analysis applying bias-correction formula in IBM SPSS Statistics for Windows, Version 29.0.0.0 (IMB Corp, Armonk, NY).

Participants

All participants were pre-informed verbally and in writing of the benefits (outcome reports) and risks (delayed onset muscle soreness) of participating before signing an informed consent document. To meet inclusion, athletes needed to be currently playing Rugby Union, registered with the New Zealand Rugby Union, and able to complete the calf muscle and sprint tests; cleared by their medical team to participate; free from current Achilles tendon injuries, current calf muscle injuries, and recent (<3 months) lower-extremity injuries. Players with an Achilles tendon rupture history were excluded.

Sixteen players from the same National Provincial Championship team were recruited through word-of-mouth and email invitations. Player characteristics are presented in Table 1. All players attended a formal familiarisation session in the two weeks before the two planned data collection sessions. For data collection, players were tested twice within the same week during their early morning training sessions (5:00 to 7:00 AM). Calf muscle power and strength-endurance were measured on the first occasion, and 10-m sprint times on the second occasion three-to-four days later. All sixteen players completed all testing procedures and there were no missing data.

Table 1. Characteristics of male Rugby Union players (*n* = 16) by playing position. Values are mean ± standard deviation and counts.

Characteristics	**Forward (*n* = 6)**	**Back (*n* = 10)**	**All (*n* = 16)**
Age (years)	22.3 ± 3.1	23.2 ± 2.6	22.9 ± 2.7
Height (m)	185.5 ± 3.8	180.8 ± 4.5	182.6 ± 4.8
Mass (kg)	99.9 ± 2.8	89.2 ± 3.8	93.2 ± 6.3
BMI (kg/m^2)	29.1 ± 1.7	27.3 ± 1.1	28 ± 1.6
Dominant (R:L)[a]	5:1	8:2	13:3

Notes. [a] Leg used to kick a ball. Abbreviations: BMI, body mass index. L, left. R, right.

Procedures

When reporting for the first testing session, participants signed an informed consent document and completed a short baseline questionnaire to ascertain meeting inclusion. Information regarding age, leg dominance (i.e., side used to kick a ball), and playing position were collected. A stadiometer (seca model 0123) and scale (seca model ESE813) were used to record body height and mass of participants barefoot to the nearest cm and 0.01 kg, respectively.

Assessment of calf muscle power and strength-endurance followed procedures previously described elsewhere (Hébert-Losier, Ngawhika, Gill, & Balsalobre-Fernandez, 2022) and used the iOS Calf Raise application version 1.5.1 (Hébert-Losier & Balsalobre-Fernandez, 2020). Before calf muscle testing, black round adhesive stickers (24 mm diameter) positioned inside white ones (32 mm diameter) were positioned below the

lateral malleolus, in line with the calcaneus. These markers would allow tracking of the vertical displacement of the foot from two-dimensional video recordings of the calf muscle tests using validated computer-vision algorithms (Fernandez, Athens, Balsalobre-Fernandez, Kubo, & Hébert-Losier, 2023; Hébert-Losier, et al., 2022). The application was calibrated using the 24 mm round sticker.

Players were required to perform three single-leg tests: 1) eccentric-concentric bodyweight power test; 2) eccentric-concentric weighted power test; and 3) concentric-eccentric strength-endurance test. All calf muscle tests were completed on the same day barefoot with the forefoot on the edge of a 20-cm high box once on the left and once on the right leg. The tests were completed in a well-light environment on a flat hard surface with the edge of the box placed 50 cm from a wall and a piece of tape on the midline of the box to indicate where players needed to place their tested foot. The test order was consistent across participants, but the test side (right or left) was randomised. Given that an initial familiarisation session can improve reliability of these testing procedures (Hébert-Losier, et al., 2022), all players had undergone a familiarisation session in the previous weeks. Players were re-familiarised with the protocol before each test and completed three supervised practice repetitions as warm-up.

Eccentric-concentric bodyweight power test

For the eccentric-concentric bodyweight power test, players stood with their forefeet on the edge of the box. Players were asked to keep the knee of their test leg straight and were allowed to place their index and middle fingertips on the wall in front of them at shoulder

height for balance support. Players then lifted both heels as high as possible, lifted the non-tested foot behind them, and needed to go “down and up” as fast as possible, returning their heel to the initial position. Players completed three repetitions, with approximately 2 seconds between repetitions. Players were given 30 seconds rest between sides. The greatest peak power (W) from any one of the three repetitions during the upwards (concentric) phase was used as the primary outcome for each leg. Data from the right and left legs were then averaged for further analysis.

Eccentric-concentric weighted power test

The eccentric-concentric weighted power test was conducted using the same setup position and repetitions as the bodyweight assessment, but players held a 35 kg dumbbell on their ipsilateral shoulder and were allowed five fingertips of their opposite hand for balance support. For comfort, a towel was placed over the shoulder. The greatest peak power (W) from any one of the three repetitions during the upwards (concentric) phase was used as the primary outcome for each leg. Data from the right and left legs were then averaged for further analysis.

Concentric-eccentric strength-endurance test

For the concentric-eccentric strength-endurance test (also known as the calf raise or heel rise test), players completed as many single-legged concentric-eccentric calf-raise repetitions as possible. Players were asked to keep the knee of their test leg straight and were allowed to place their index and middle fingertips on the wall in front of them at

shoulder height for balance support. Players then lifted and lowered their heel to the beat of a 60 beats per minute metronome, raising their heel as high as possible in one beat and lowering it in one beat (i.e., 30 repetitions per minute). The test was stopped when players could no longer complete a repetition, keep to the beat of the metronome, or maintain form (i.e., started to demonstrate compensatory movements or marked reduction in heel range of motion). Consistent verbal encouragement was provided during testing. After a two-minute rest, the test was repeated on the alternate leg. The number of repetitions (*n*), peak upward displacement from the initial position (cm), total positive displacement (cm), and total positive work (J) were used as the primary outcomes for each leg. These data were extracted from the position curve of the Calf Raise application, where the position of the 24 mm marker in the first video frame (i.e., bottom of the calf raise) defines zero. Data from the right and left legs were then averaged for further analysis.

An iPad (model A1822, Apple Inc., California, USA) running iOS 14.1 was placed 50 cm from the foot of participants in portrait orientation to track the black marker through the full range of motion. The Calf Raise application (version 1.5.1) tracked videos at 60 frames per seconds (Hébert-Losier & Balsalobre-Fernandez, 2020). A single investigator conducted all testing and analysed all videos. The application has demonstrated good-to-excellent validity for all test outcomes derived in Rugby Union players against 3D motion capture and force plate data (intra-class correlation, ICC: 0.84 to 1.00; coefficient of variation, CV: 0 to 6.6%) (Hébert-Losier, et al., 2022). The inter-rater reliability of application use has been reported as excellent for all three tests (ICC $\geq$ 0.93, CV $\leq$ 5%) (Hébert-Losier, et al., 2022). Furthermore, the test-retest reliability of these three tests

performed in Rugby Union players has also been reported as good across metrics following a familiarisation session (ICC ≥ 0.83, CV ≤ 9.8%) (Hébert-Losier, et al., 2022).

10-m sprint times

Three-to-four days after calf testing, the 10-m sprint times of players were assessed indoors on an artificial turf using single-beam timing lights (Brower Timing System, Utah, USA). The first gate was set at a height of 0.5 m, while the 10-m gate was set at a height of 0.75 m. Before the sprints, players completed a 10-minute standardised warm-up that involved jogging, dynamic stretching, running drills, and stride-outs. All players performed 10-m sprint performance tests weekly as part of their team's monitoring practices and were familiar with the sprinting procedures.

Players began the 10-m maximal effort sprints 0.5 m behind the first gate from a standing split position. Players were told to "run as fast as possible" past the last gate. Each player performed a minimum of three sprints, with at least 60 seconds rest between trials. Players were permitted additional trials (up to six in total) if they felt they could perform better. Sprint times were measured to the nearest 0.01 second. The 10-m time was used as an indicator of short sprint and acceleration ability, which has demonstrated excellent test-retest reliability in Rugby players (ICC = 0.90) (Goodale, Gabbett, Stellingwerff, Tsai, & Sheppard, 2016), with small typical errors (< 1%) (Duthie, Pyne, Ross, Livingstone, & Hooper, 2006). For each player, average and best sprint-time values were extracted.

Statistical analysis

Descriptive statistics were computed for all variables, and normality of distribution confirmed using Kolmogorov-Smirnov ($p \geq 0.087$). Pearson correlations and 95% confidence intervals [lower, upper] between sprint times (average of all trials and best trial) and calf muscle test metrics were computed, with estimates based on Fisher's z transformation with bias adjustment. Correlations were considered *small*, *moderate*, and *large* when the absolute *r* value reached 0.10, 0.30, and 0.50, respectively (Cohen, 1992). Correlations were deemed *unclear* if the 95% confidence interval overlapped the threshold for small positive ($r = 0.10$) and small negative ($r = -0.10$) correlations. Scatterplots with simple linear regression lines and R-squared values (R^2) were constructed in Excel® for Microsoft 365 MSO (version 2302, Microsoft Corp, Redmond, WA) to provide visual representation of individual data and the relationship between variables. The same statistical approaches were used to explore the potential relationship within calf muscle metrics. All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 29.0.0.0 (IMB Corp, Armonk, NY) and Excel® with the significance level set at $p \leq 0.05$.

RESULTS

Sprint times and calf muscle test metrics are presented in **Table 2**. There were *large* significant correlations between average 10-m sprint times and calf muscle power (bodyweight and weighted) and strength-endurance (total displacement and total work) metrics (**Table 3**). There were *large* significant correlations between best 10-m sprint times and calf muscle power (weighted) and strength-endurance (peak displacement, total

displacement, and total work) metrics (**Table 3**). For the significant correlations, R^2 values ranged from 0.253 to 0.395 (**Figure 1**).

Table 2. 10-m sprint times and calf muscle metrics of male Rugby Union players (*n* = 16). Values are mean ± standard deviation.

Metric	**All (*n* = 16)**
10-m sprint times	
Average (s)	1.69 ± 0.06
Best (s)	1.64 ± 0.09
Calf muscle metrics	
Bodyweight power (W)	653.9 ± 93.0
Weighted power (W)	655.6 ± 112.6
Strength-endurance (repetitions, *n*)	21.1 ± 4.8
Strength-endurance (peak *d*, cm)	10.3 ± 1.9
Strength-endurance (total *d*, cm)	216.7 ± 50.4
Strength-endurance (total work, J)	2153.8 ± 497.0

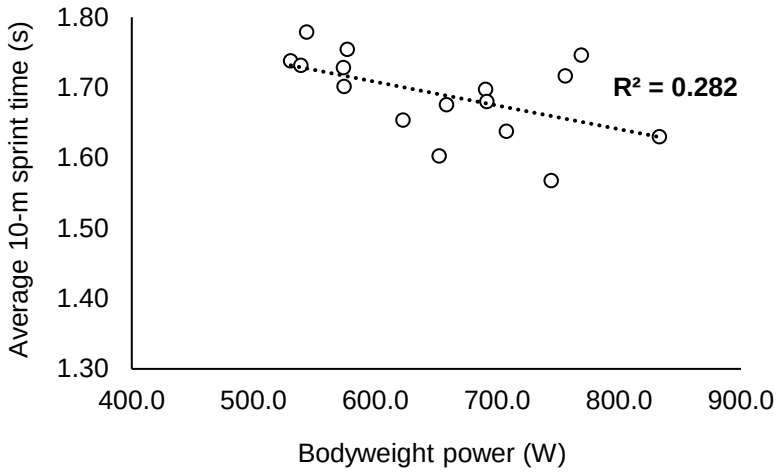
Notes. Abbreviations: *d*, displacement.

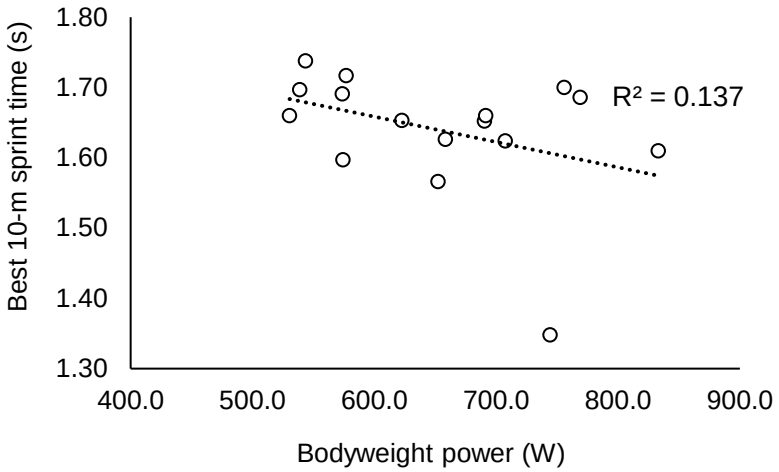
Table 3. Correlations between 10-m sprint times and calf muscle metrics of male Rugby Union players (*n* = 16). Values are Pearson correlations and 95% confidence intervals [lower, upper] with bias adjustment.

Calf muscle metrics	**10-m sprint times**	
	Average (s)	Best (s)
Bodyweight power (W)	-0.531 [-0.807, -0.031] ***p* = 0.034**, *large*	-0.370 [-0.726, 0.166] *p* = 0.158, *unclear*
Weighted power (W)	-0.628 [-0.851, -0.173] ***p* = 0.009**, *large*	-0.527 [-0.805, -0.025] ***p* = 0.036**, *large*
Strength-endurance (repetitions, *n*)	-0.282 [-0.677, 0.257] *p* = 0.289, *unclear*	-0.291 [-0.683, 0.248] *p* = 0.273, *unclear*
Strength-endurance (peak *d*, cm)	-0.413 [-0.748, 0.118] *p* = 0.112, *moderate*	-0.512 [-0.797, -0.004] ***p* = 0.043**, *large*
Strength-endurance (total *d*, cm)	-0.505 [-0.794, 0.005] ***p* = 0.046**, *large*	-0.505 [-0.794, 0.005] ***p* = 0.046**, *large*
Strength-endurance (total work, J)	-0.545 [-0.814, -0.05]	-0.503 [-0.793, 0.007]

	***p* = 0.029**, *large*	***p* = 0.047**, *large*

Notes. Significant *p*-values ($p \leq 0.05$) are **bolded**. Correlations considered *small*, *moderate*, and *large* when absolute *r* values reached 0.10, 0.30, and 0.50 (Cohen, 1992). Correlations considered *unclear* when the confidence interval overlapped *small* positive and negative thresholds. Abbreviations: *d*, displacement.


Average 10-m sprint time (s)
1.80
1.70
1.60
1.50
1.40
1.30
400.0
500.0
600.0
700.0
800.0
900.0
Bodyweight power (W)
R² = 0.282


Best 10-m sprint time (s)
1.80
1.70
1.60
1.50
1.40
1.30
400.0
500.0
600.0
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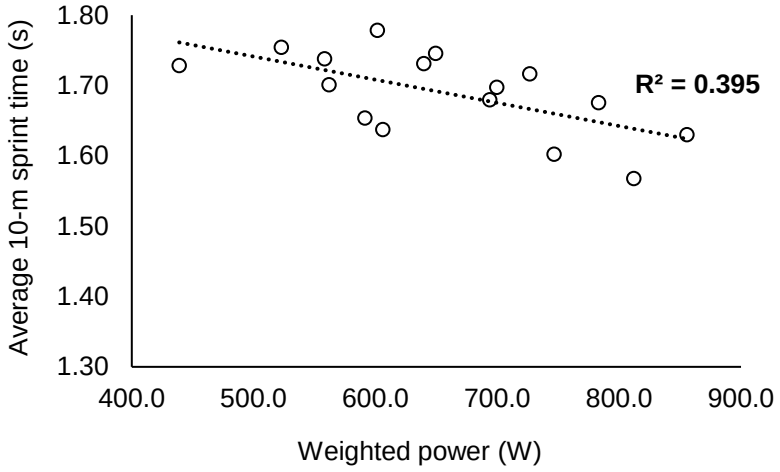
800.0
900.0
Bodyweight power (W)
R² = 0.137


Average 10-m sprint time (s)
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1.70
1.60
1.50
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1.30
400.0
500.0
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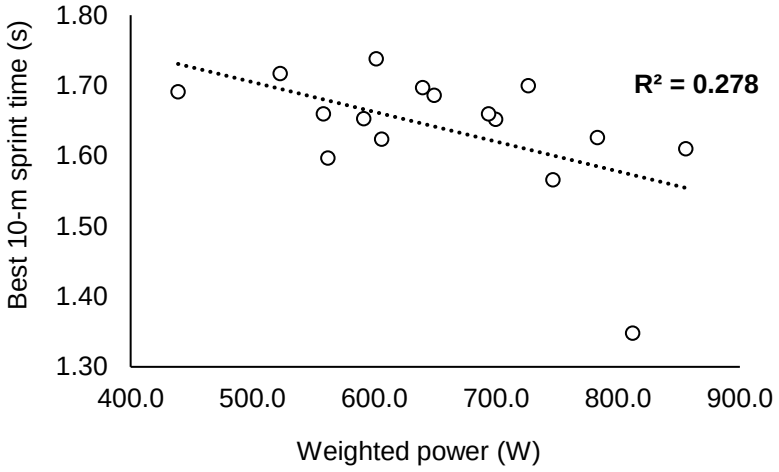
900.0
Weighted power (W)
R² = 0.395


Best 10-m sprint time (s)
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1.70
1.60
1.50
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1.30
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600.0
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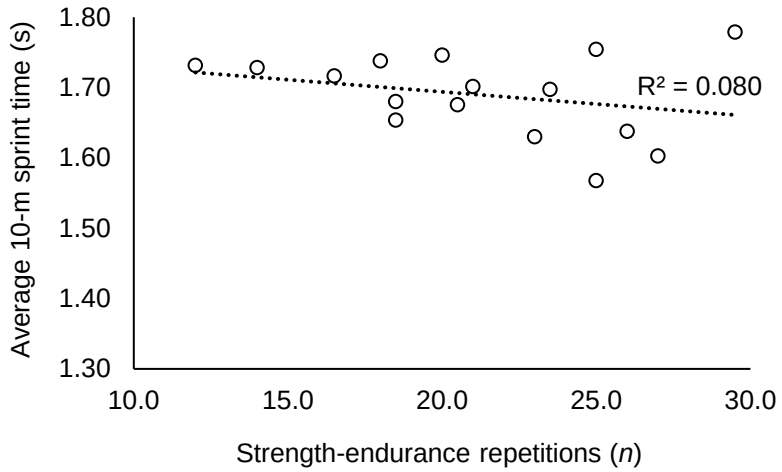
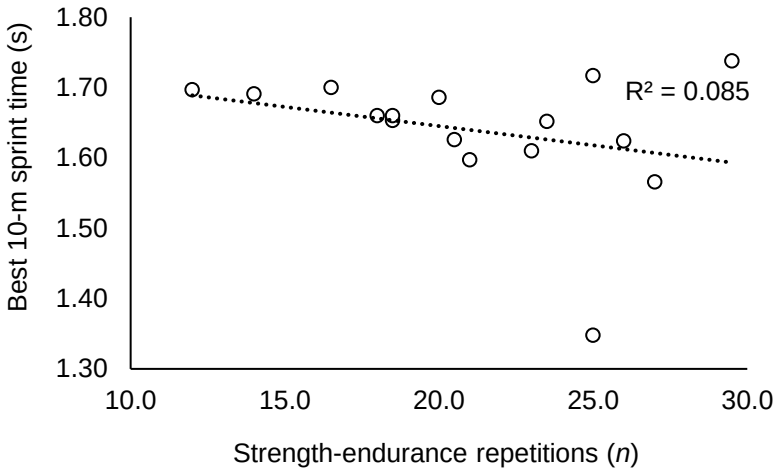
800.0
900.0
Weighted power (W)
R² = 0.278


Average 10-m sprint time (s)
1.80
1.70
1.60
1.50
1.40
1.30
R² = 0.080
10.0
15.0
20.0
25.0
30.0
Strength-endurance repetitions (n)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1.70
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1.30
R² = 0.085
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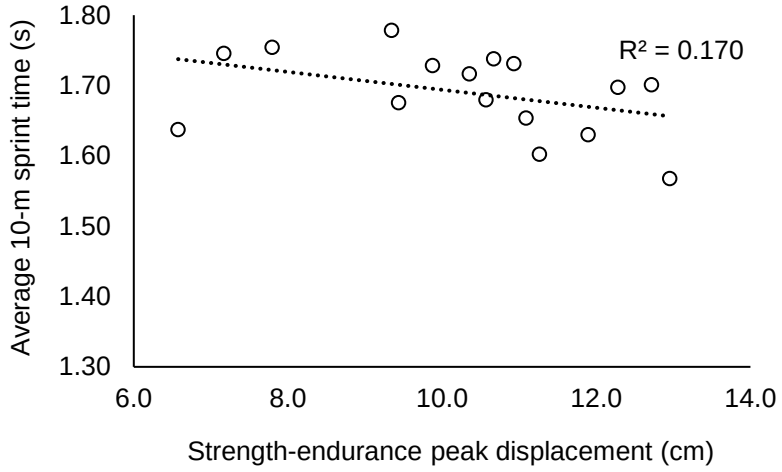
30.0
Strength-endurance repetitions (n)


Average 10-m sprint time (s)
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1.70
1.60
1.50
1.40
1.30
R² = 0.170
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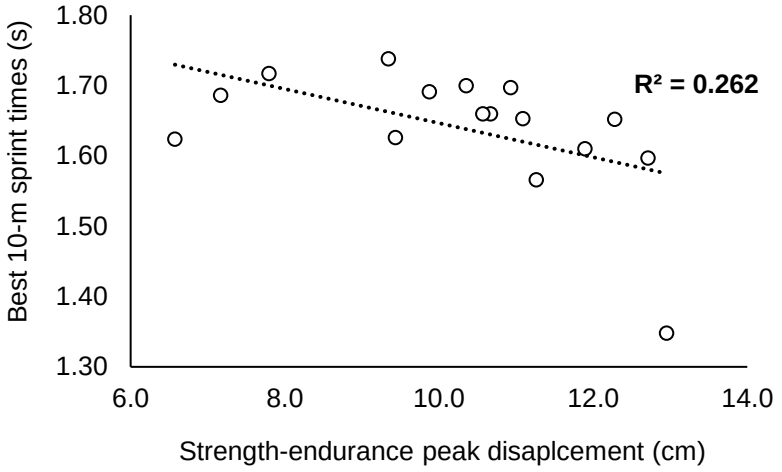
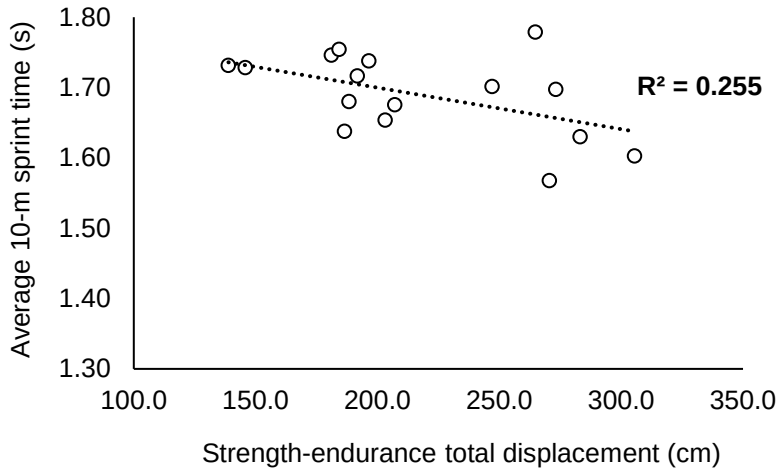
8.0
10.0
12.0
14.0
Strength-endurance peak displacement (cm)


Best 10-m sprint times (s)
1.80
1.70
1.60
1.50
1.40
1.30
R² = 0.262
6.0
8.0
10.0
12.0
14.0
Strength-endurance peak disaplcement (cm)


Average 10-m sprint time (s)
1.80
1.70
1.60
1.50
1.40
1.30
100.0
150.0
200.0
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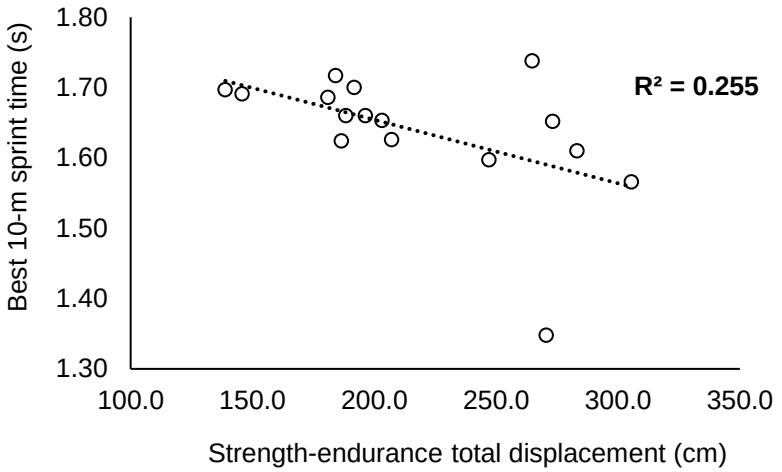
300.0
350.0
Strength-endurance total displacement (cm)
R² = 0.255


Best 10-m sprint time (s)
1.80
1.70
1.60
1.50
1.40
1.30
100.0
150.0
200.0
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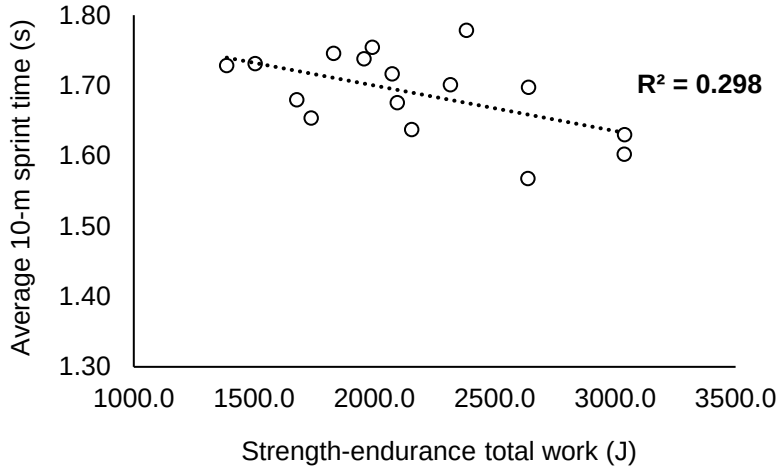
Strength-endurance total displacement (cm)
R² = 0.255


Average 10-m sprint time (s)
1.80
1.70
1.60
1.50
1.40
1.30
1000.0
1500.0
2000.0
2500.0
3000.0
3500.0
Strength-endurance total work (J)
R² = 0.298

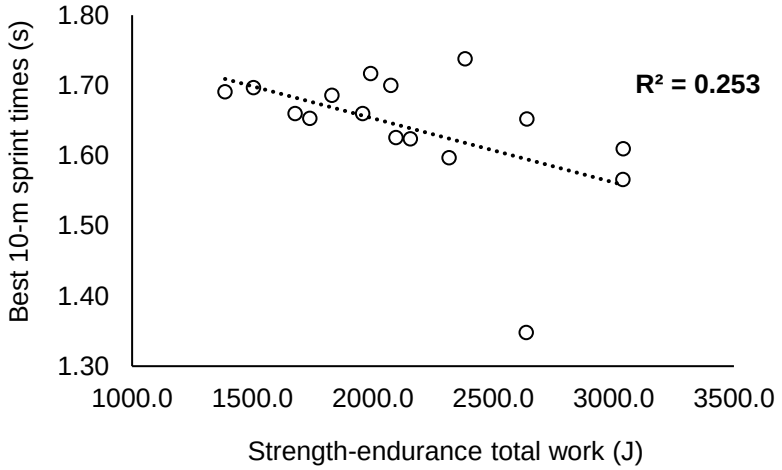

Best 10-m sprint times (s)
1.80
1.70
1.60
1.50
1.40
1.30
1000.0
1500.0
2000.0
2500.0
3000.0
3500.0
Strength-endurance total work (J)
R² = 0.253

Figure 1. Scatterplots of average (left column) and best (right column) 10-m sprint times against calf muscle power and strength-endurance metrics. Linear trend lines and variance explained (R^2) values are provided on plots. Significant correlations are **bolded**.

Exploratory analysis of the relationship within calf muscle metrics revealed *large* significant correlations between bodyweight and weighted power, as well as weighted power and strength-endurance metrics (total displacement and total work). All strength-endurance metrics were largely correlated to one another ($p \leq 0.039$), except for peak displacement and total work. Total displacement and total work were almost perfectly related ($r = 0.943$). Data are provided as supplementary material.

DISCUSSION

This is the first study to compare power and strength-endurance of the plantarflexors with 10-m sprint times in Rugby Union players. We observed a *large* significant relationship between calf muscle weighted power and strength-endurance (total displacement and total work) metrics, and 10-m sprint times (average and best trials). The relationship between calf power, calf strength-endurance, and sprint metrics corresponds to what is already known about the importance of plantarflexor force to sprint acceleration (Pandy, et al., 2021), and aligns with previous findings of *large* correlations between maximal calf muscle strength and 5 – 10 m split times in physical education students (Möck, et al., 2018). Preliminary work in cricket has also identified a relationship between greater isometric plantarflexor force and sprints associated with simulated runs between wickets during cricket batting innings (Houghton, Dawson, & Rubenson, 2013). Furthermore, there were *large* correlations within calf muscle metrics, especially between the two power tests and within the strength-endurance metrics. All considered, our data overall suggest that weighted peak power and total work during strength-endurance testing are

the two metrics most likely to provide insight on short sprint and sprint acceleration abilities in Rugby Union players.

In the return-to-sport continuum, maximum force-generating and strength-endurance abilities are deemed as important aspects of the rehabilitation process (Green, et al., 2022). Our data reinforce that dynamic plantarflexor function (power and strength-endurance) is linked with short sprint and acceleration abilities – which are athletic performance markers. Hence, the triceps surae muscle-tendon unit is not only an area of concern for rehabilitation specialists, but also a focus for strength and conditioning coaches. Compliance with injury prevention programmes negatively affects outcomes (van Reijen, Vriend, van Mechelen, Finch, & Verhagen, 2016) and is deemed critical in addressing injury incidence (Chebbi, Chamari, Van Dyk, Gabbett, & Tabben, 2022). The fact that calf muscle abilities are related to athletic performance markers might serve as a motivating factor for calf muscle exercise adherence when prescribed with the goal of reducing calf muscle and Achilles tendon injury incidence.

The lack of a strong relationship between the number of repetitions and peak displacement reached during the strength-endurance test and sprint abilities is not surprising. The number of repetitions fails to account for the mechanical work and is typically a poor reflection of function as some individuals may move a limited distance due to a limited range of ankle motion, compromised functional ability of their plantarflexors, or the effects of fatigue. Peak displacement is also a metric that does not reflect the construct of the strength-endurance test and does not encapsulate the ability of a person to move their bodyweight repeatedly. These two metrics were not only poorly related to sprint

performance, but they were also poorly related to each other. Yet, when combining the number of repetitions completed and positive displacement during each repetition, a strong relationship between metrics of calf muscle strength-endurance function (i.e., total displacement and total work) and athletic ability emerged. As total displacement and total work metrics were almost perfectly correlated, we recommend using total work as it also considers the body mass displaced during strength-endurance testing. Our findings again highlight the clinical value of monitoring the total work completed when implementing the concentric-eccentric strength-endurance (i.e., calf raise) test, and that the number of repetitions alone is not a useful clinical indicator of calf muscle function (Silbernagel, Nilsson-Helander, Thomeé, Eriksson, & Karlsson, 2010).

The weighted power test had the strongest relationship to 10-m sprint times (both average or best trials) and is therefore perhaps the one with the most utility for approximating short sprint and acceleration abilities in Rugby Union. This test is also quicker to complete than the strength-endurance one and there is generally less concern of delayed onset muscle soreness from power than strength-endurance testing. However, it is worth considering that the standardised additional 35 kg load will have varied as a percentage of bodyweight and there is potential for standardising the external loads to an individuals' bodyweight. That noted, a set external load is easier to implement and quickens testing, which may be more transferable to a larger study and testing large number of players within squads. Future work is needed to clarify if using a relative load based on an individual's mass would provide more meaningful results than using a set load.

Limitations

The major limitations of this work are the small sample size and lack of representation across playing positions given the known differences in positional demands on-field (Bridgeman & Gill, 2021) and off-field (Hébert-Losier, et al., 2022). This study was powered to detect *large* effect size differences. A larger sample would allow to detect smaller effect sizes and potentially provide narrower confidence estimates for the correlations. Furthermore, the focus of this project on elite level performers is important as novice players are likely to experience more variance in sprint speeds due to various other factors.

The causal relationship between short sprint abilities and plantarflexor power and strength-endurance is unclear as it may be that sprinting improves plantarflexor power and strength-endurance or that "good" plantarflexor power and strength-endurance improves short sprint abilities. Further research is needed to see if increasing plantarflexor power and/or strength-endurance improves sprint abilities. It may also be that there is a ceiling or marginal gains effect wherein greater plantarflexor power and strength-endurance abilities translate to no or minimal gain in short sprint abilities. It could be interesting to explore the relationship between calf-strength metrics and sprint performance following different training interventions. As this study was cross-sectional in nature, it is not possible to determine if calf muscle power and strength-endurance abilities are related to future Achilles tendon or calf muscle injuries.

Practical applications

The association between calf muscle power and sprint times supports the available evidence related to the role of the plantarflexors in acceleration. These data could be of use for elite performance and strength and conditioning coaches to improve plantarflexor function and sprint speeds. Targeting strength-endurance and weighted power qualities of the plantarflexors may lead to improvements in on-field performance, with the measures used allowing an easy way to monitor response to interventions that target plantarflexor performance.

It is possible that tissue adaptations linked with the development of plantarflexor power and strength-endurance are beneficial for mitigating risk of triceps surae muscle and Achilles tendon injuries. The fact that calf muscle metrics are related to athletic performance markers might motivate players to adhere to regular calf muscle monitoring and training programmes, with likely benefits on injury incidence.

CONCLUSIONS

Our study is one of a limited number of studies that have investigated the relationship between plantarflexor function and athletic performance. Our preliminary work investigating triceps surae muscle strength-endurance and power reveals *large* relationships with 10-m sprint times in Rugby Union players. Our findings emphasise the potential importance of triceps surae muscle strengthening for short-sprint and acceleration abilities in Rugby Union. Based on the strong relationships observed and the easy-to-use nature of the assessment procedures, practitioners could target and monitor improvements in plantarflexor performance function in gym or clinical settings, which

may influence sprint performance. Further research is required to determine the potential relevance and implications of these plantarflexor metrics in return-to-play post injury and injury prevention strategies.

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Conflict of interest

Two of the authors (KHL, CB) developed the free-to-use Calf Raise application. The data from the application were obtained from an independent researcher (TN) not related to the development of the application.

Ethical approval

The Human Research Ethics Committee of the University of Waikato [HREC(Health)2020#11] approved the research prior to data collection, which adhered to the Declaration of Helsinki. All participants signed a written informed consent document that explained the potential risks (delayed onset muscle soreness) and benefits (individualised reports) associated with testing.

Author Contributions

Conceptualization & Methodology: KHL. Software: KHL, CBF. Data Curation: KHL, TN. Formal Analysis: KHL, TN, CBF, SO. Investigation: KHL, TN. Project Administration: KHL. Resources: KHL. Supervision: KHL. Visualization: KHL, SO. Writing – Original Draft Preparation, Review & Editing: KHL, TN, CBF, SO. Final Approval: KHL, TN, CBF, SO.

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