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Inter-correlations between Laboratory and Field-based Tests of Muscle Contractile Power

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ABSTRACT

International Journal of Exercise Science 9(5): 635-645, 2016. Muscle contractile properties have previously been distinguished by fiber typing muscle samples obtained from needle biopsy; however due to conflicting evidence regarding sampling bias and the related need for multiple biopsies, it is not certain if these results are a reliable reflection of whole muscle fiber type expression. Inter-correlations between laboratory and field-based measures of muscle contractile power were used to determine which assessments best discriminate between participants of varying sprint performance, and indirectly reveal potential for power vs. endurance exercise performance. Healthy active male (n=32) and female (n=17) participants were recruited from the Central West region of New South Wales. Isometric rate of force development (RFD) and isokinetic torque were assessed at different velocities. A counter movement jump (CMJ) test was implemented to assess concentric and eccentric RFD. A modified Wingate test was used to assess peak power expressed as Watts using a stationary start to the onset of decreased cadence. A 20m sprint was used as a field-based measurement of exercise performance, recording split times at 2m, 10m and 20m, and interval times from 2-10m, 2-20m, and 10-20m. Over 85% (r^2=0.851) of 10-20m sprint running performance variance was significantly accounted for by a multiple regression model consisting of peak Watts per kilogram body mass during the modified Wingate (pkWkg), sex, and peak concentric rate of force development (pkcRFDkg). Results indicate a highly significant and predictive relationship between performance measures assessed by the modified Wingate test and sprint running performance in both males and females. Laboratory power tests alone seem sensitive enough to ascertain suitability for power vs. endurance performance potential.

KEY WORDS: Sprint running, force, fibres, genetics, cycling

INTRODUCTION

Sprint running is considered an important component of athletic performance (3) and is commonly used as a assessment in many individual and team sports. During the initial phases of sprint running, the ability to generate a large concentric force and create high velocity

during acceleration is essential (17). This suggests individuals with the ability to rapidly generate higher amounts of concentric force will perform better during sprint running. Further, the action of sprint running consists of what is known as stretch-shortening cycle (SSC) movements (12), which involves the rapid contraction of a muscle immediately after it has been lengthened. If relationships between muscular contractile properties and sprint running can be identified, an individuals' sprint running performance may be predicted by assessing their muscular performance properties, and vice-versa. Muscle contractile power measurements such as torque, concentric and eccentric rate of force development (RFD), and peak levels of power output (Watts) and RPM, will be assessed to determine potential relationships between sprint running performance.

While the primary purpose of this research is to identify relationships between laboratory based measures of muscular power to sprint running performance, it is important to note that there is increasing evidence confirming genetic factors play the largest role on human muscle fiber type expression (25); with subsequent influences on athletic performance i.e. muscle contractile measures. From this we could speculate that individuals possessing the above characteristics are comprised of a greater percentage of fast-twitch (FT) muscle fibers and are able to create larger amounts of force from the lower limbs in a shorter time frame, culminating in greater power. This is understandable based on the nerve, muscle structure and energetics that typify FT motor units (4).

Therefore out of additional interest, the authors wish to bring to light the bias that exists around the needle muscle biopsy when used to typify muscle fibre type, and propose alternative methods. There is clear empirical evidence for the need for multiple muscle biopsies to remove sampling bias in muscle fiber typing and related interpretations for talent identification (6). For example, muscle biopsies are often only used to sample small groups of fibers at a time (100-250 fibers), yet such samples are not a true representation of muscle fiber type proportions in whole muscle. This is explained by the large variability in the spatial distribution of fiber types within a whole muscle (14, 15, 27).

The purpose of this study was to assess the relationship between laboratory and field based tests of muscular performance, while avoiding the intrusiveness and potential sample limitations of the needle biopsy. Again it must be noted that since muscle biopsies were not taken, this is simply an inquiry that will require further research dependent on our findings. It was hypothesized that strong correlations would be shown for select measures of muscular power and sprint running, and that from this, high predictive accuracy would result for a combination of these variables to sprint running performance.

METHODS

Participants

The study consisted of 49 healthy active male (n=32) and female (n=17) participants (mean age = 24.5yr, height = 173.7cm, mass = 79.5kg) who were recruited from the Central West region of New South Wales (table 1). Prior to and during the data collection period, each participant was

partaking in sprint and/or lower body resistance training more than three times per week. Written informed consent was obtained from each participant prior to data collection and all methods were approved by the institution's Human Research Ethics Committee.

Table 1. Cohort descriptives.

	N	Mean ± Std. Deviation
Age	49	24.57 ± 7.5
Height	49	173.7 ± 20.76
Weight	49	79.51 ± 12.26
Load	49	6.75 ± 1.05
PkWatts	49	756.04 ± 216.73
PkRPM	49	113.51 ± 24.49
TimePP	49	8.27 ± 1.87
PkWkg	49	9.45 ± 2.03
Run2	49	0.62 ± 0.68
Run10	49	2.06 ± 0.17
Run20	49	3.54 ± 0.34
Run2to10	49	1.43 ± 0.12
Run2to20	49	2.92 ± 0.3
Run10to20	49	1.48 ± 0.17
PeccRFD	49	1628.38 ± 796.52
PconcRFD	49	975.67 ± 395.97
PkT180	49	102.22 ± 38.28
Tslope	49	-0.29 ± 0.12
IsoRFD	49	763.79 ± 354.98
PkT180kg	49	1.28 ± 0.41
PkcRFDkg	49	12.26 ± 4.52
PkeRFDkg	49	20.32 ± 9.04

Protocol

Four different measures of muscular performance were chosen as the experimental tasks. Each participant completed the tasks in random order. Total testing time per participant was approximately 90 min; with the completion time of each test lasting 10 minutes on average. Participants were given 15 minutes of rest between each test item in order to increase the internal validity of test results.

The isokinetic test was performed using the HUMAC NORM Isokinetic Extremity System. Participants were assigned to sit in the computerised muscle function testing system, where force levers were then attached to the participants' dominant lower leg, which was selected based on participant response. The system was set and the participant was instructed to produce maximal muscle contraction (extension) of the dominant knee at designated speeds ranging from 90-350 degrees per second (°/s) increasing at 30°/s increments. Following a five-repetition warm up against a moderate velocity of 180°/s, nine sets were completed in order from slowest to fastest velocity, each consisting of five repetitions. Participants had 30 seconds of seated passive recovery between each set of 5 maximal effort contractions.

The isometric test of muscle contraction was also performed using the HUMAC NORM Isokinetic Extremity System. The procedure was similar to that described above; however maximal effort contractions were applied against an immovable resistance, where the force applied to the lever arm was then recorded by the instrument. The lever arm was set to 75° for each participant. Once set, participants completed 5 repetitions of 5 s maximal effort isometric contractions, where 10 s rest was given between each effort. Data were acquired using a custom developed program (LabVIEW, National Instruments, Austin, TX) where calibrated and gravity corrected force signals were acquired continuously during the 5 s contraction bouts.

The counter movement jump (CMJ) was used to assess eccentric and concentric rate of force development (RFD). Participants stood on a force platform, and were then instructed to squat down and jump into the air as fast as possible. The participants' hands were placed on their hips and thus arms were not utilized in the jump. The force profile during this movement was acquired at 200 Hz by the commercial software (Ballistic Measurement System, or BMS, Innervations, USA) via a USB data connection. Following a three-repetition warm up, participants were required to complete three successful CMJs within a 15 s time period. The trial with the largest peak force was used in statistical analyses.

Participants performed a 20m sprint, where each was required to sprint through four timing gates to quantify the time to complete 2m, 10m and 20m of sprinting from a stationary start. Following a three-repetition warm up at approximately 50%-80% of the participants' individual maximal effort, each participant completed 3-6 successful trials. The fastest trial was used in the statistical analyses.

A modified Wingate Cycle Ergometer test was used as to quantify peak power, time to peak power, and peak cadence. Participants cycled from a stationary start on a plate loaded stationary cycle ergometer (Monark 894 E) against a predetermined resistance (kg resistance = body mass x 0.085). Following a 2 minute rest period after a five minute warm up against no resistance at 60 rev/min, participants were required to commence cycling against this resistance as hard and fast as possible. When the participant's cadence decreased below maximal intensity (~10-15 s), the participant was required to stop cycling and commence an active recovery against no resistance.

Statistical Analysis

HUMAC and CMJ data were processed using custom-designed software (LabVIEW, National Instruments, Austin, TX). For isokinetic measures, contractions for each velocity were custom processed to identify the peak torque. The contraction with the highest peak torque for each velocity setting was used in subsequent statistical analyses, and to derive a torque to contractile velocity regression slope as an added independent variable in the regression analyses. For isometric force, each contraction peak force was identified and the highest was used as the maximal voluntary contraction. For this contraction, the linear increase in force was fit with linear regression, and the slope was used as the rate of force development. Due to the large variability in the profile of this force response, no standard time interval was used for

this regression analysis. For all participants, the linear portion of the force profile was selected manually, which for most participants occurred after 75 ms of contraction. For the Wingate data, peak watts, peak power, and peak rev/min was calculated in a second LabVIEW program for the maximal effort cycle.

All data were first transferred to a commercial spreadsheet program (Excel, Microsoft Corporation) for screening and specific variable conversion to relative (to body mass) measures. Data were then imported to a commercial statistical program (SPSS, V20, IBM) for subsequent statistical analyses. First, bivariate correlations between all variables were completed and assessed for significance. From these, the dependent sprint variable was selected based upon the highest correlations to the majority of remaining variables. Stepwise multiple regression was performed on a selection of the independent variables, as explained in Results, to establish the detection of variables that combined to significantly explain as large a proportion of the variability sprint performance (dependent variable) as possible.

RESULTS

The bivariate correlation matrix (see table 2) indicated many significant relationships between sprint running performance and multiple physiological variables. Based on these results, the sprint time from 10 to 20m was selected as the best dependent variable and used in subsequent reporting of bivariate correlations and the subsequent multiple regression analysis. Peak watts per kilogram of body mass (PkWkg) from the modified Wingate test was the single best predictor of 10 – 20m sprint running performance, closely followed by peak cadence (PkRPM) and isokinetic peak torque at 180^0/kg of body mass (PkT180/kg). Each showed significant correlations between all six variables of sprint performance including 10m, 20m, 2-20m, 2-10m, and 10-20m ($p<0.001$, $p<0.001$, $p<0.001$, respectively) and 2m ($p<0.006$, $p<0.008$, $p<0.008$, respectively). The CMJ identified the most significant correlations between peak concentric rate of force development per kilogram of body mass (pkcRFDkg) and all measures of running performance except 2m, the highest being 10-20m ($p<0.001$). Similarly isometric RFD (IsoRFD) reported significant correlations against the same running measures, the highest being 2-20m ($p<0.001$).

In addition to the dependent variable of 10-20m sprint performance, a subset from the 17 remaining variables were used, selected based on physiological relevances to exercise performance. These included pkRPM, timePP, pkWkg, pkT180, pkcRFD, Tslope, age, and sex. The stepwise multiple regression model then used these to ascertain unique variance explanation and revealed the three independent variables used in the model. The multivariate model revealed three significant independent variables; PkWkg, sex, pkcRFDkg as presented in table 3. From these variables, an explanatory equation model was developed (see Equation 1 and Figure 1).

Table 2. Bivariate correlations matrix.

		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1.	Pk RPM	1	-	0.99	-	-	-	-	-	-	-	0.51	0.74	0.34
		<0.0	0.01	<0.0	0.00	<0.0	<0.0	<0.0	<0.0	<0.0	0.02	<0.0	<0.0	0.01
2.	Time PP		1	-	0.12	0.21	0.28	0.26	0.29	0.33	0.34	-	-	0.04
			<0.0	0.01	0.39	0.13	0.04	0.06	0.03	0.01	0.01	0.00	<0.0	0.77
3.	Pk W/kg			1	-	-	-	-	-	-	-	0.52	0.75	0.33
				<0.0	0.00	<0.0	<0.0	<0.0	<0.0	<0.0	0.02	<0.0	<0.0	0.02
4.	Run2				1	0.73	0.66	0.50	0.53	0.53	0.22	-	-	-
					<0.0	<0.0	<0.0	<0.0	<0.0	<0.0	0.11	0.22	0.00	0.23
5.	Run10					1	0.96	0.90	0.92	0.83	0.35	-	-	-
						<0.0	<0.0	<0.0	<0.0	<0.0	0.01	0.00	<0.0	0.03
6.	Run20						1	0.95	0.98	0.95	0.35	-	-	-
							<0.0	<0.0	<0.0	<0.0	0.01	0.00	<0.0	0.00
7.	Run2to10							1	0.97	0.92	0.30	-	-	-
								<0.0	<0.0	<0.0	0.03	0.00	<0.0	0.00
8.	Run2to20								1	0.96	0.34	-	0.72	-
									<0.0	<0.0	0.01	0.00	<0.0	0.00
9.	Run10to20									1	0.31	-	-	-
										<0.0	0.02	0.00	<0.0	0.00
10.	Tslope										1	-	-	-
											<0.0	0.00	0.00	0.55
11.	IsoRFD											1	0.49	-
												<0.0	<0.0	0.83
12.	PkT180/kg												1	0.33
													<0.0	0.01
13.	PkconcRFD /kg													1
														<0.0

Top value = r; Bottom value = p

Table 3. Stepwise multiple regression model.

Model		Unstandardised Coefficients		t	Sig.	R	R Square
		B	Std. Error				
1	(Constant)	2.163	0.056	38.843	.881[a]	.881[a]	0.776
	PkWkg	-0.072	0.006	-12.483	.910[b]		
2	(Constant)	1.843	0.101	18.334	.923[c]	.910[b]	0.828
	PkWkg	-0.054	0.007	-7.619	0		
	Gender	0.11	0.03	3.651	0.001		
3	(Constant)	1.883	0.096	19.639	0	.923[c]	0.851
	PkWkg	-0.05	0.007	-7.342	0		
	Gender	0.107	0.028	3.773	0		
	PkcRFDkg	-0.006	0.002	-2.581	0.013		

a. Predictors: (Constant), PkWkg; b. Predictors: (Constant), PkWkg, Gender; c. Predictors: (Constant), PkWkg, Gender, PkcRFDkg; d. Dependant Variable: Run10to20

Equation 1. Explained sprint time (10-20m)

(1.883 - .05 x PkWkg) + .107 x sex - .006 x PkcRFDk

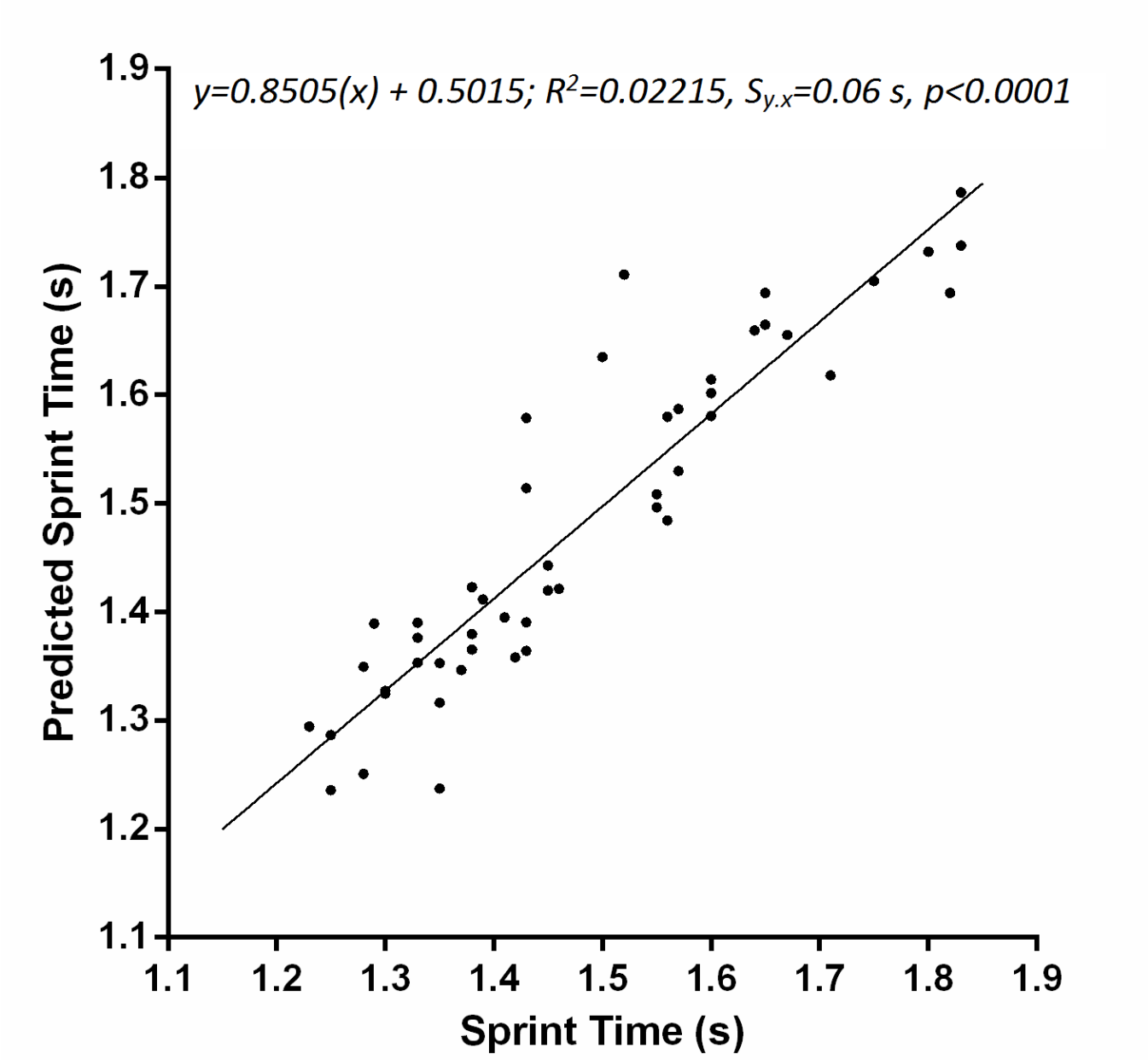

Figure 1. Explained sprint time (10-20m).

DISCUSSION

The major findings from the bivariate correlations demonstrate muscular power components measured from cycle ergometry as the best predictors of sprint running performance. While pkW showed significant correlations with all sprint running measures, results showed more significance with each measure when body mass was taken into account (pkWkg). The second significant variable, pkRPM, was likely due to the similar performance components required for both modalities. That is, much like sprint running, achieving high pkW and pkRPM requires high contractile RFD to support high contractile power, leg turnover and propulsion.

It should be noted that despite the difference in modalities, the modified version of the Wingate anaerobic test used in the study has clear predictive implications to sprint running performance, and may well be a good indicator of FT muscle fiber expression of the quadriceps muscles. Again this is speculation and further research is needed, as no measures of fibre type were taken in the study. The test implemented was simple, non-invasive, inexpensive to develop and operate, and completed in less than 30 seconds.

Perhaps the most consistent finding was the significant relationship between concentric RFD and sprint running. Accounting for body mass (pkcRFDkg) again showed increased significance between all measures. These findings support previous research that has identified the relationship between concentric RFD and sprint running performance (11, 24, 26). No significant relationship was found between eccentric RFD and sprint running performance, which is also consistent with these findings. This is likely due to the fact that the eccentric phase of the CMJ is much slower than the eccentric phase of a sprint action and more likely to be a measure reflective of strength and not power (24).

Isometric RFD is considered to be an important indicator of dynamic athletic performance such as sprinting or jumping (1, 10, 22). Significant relationships were identified in all measures of sprint running performance except 2m. While dynamic and isometric measures of strength are thought to be related (7), dynamic strength is likely to be more specific to athletic performance (5). This might explain in part why strong relationships were found in all measures of sprint running except during the initial explosive phase. Despite the distinct neural and mechanical differences associated between dynamic movements and isometric force production (23), the results from the present study confirm a strong relationship between the two. This is consistent with recent findings by Tillin et al. (23).

Alexander (2) suggested sprint running performance is a direct result of the impulse applied to the ground during the propulsion phase of the stride; where the force generated is directly related to the power capabilities of the hip flexors and extensors, knee extensors and plantar flexors. It can be thought then that athletes who create greater amounts of torque through these muscle groups will produce faster sprint times. In the current study, the isokinetic rate of contraction and torque (Tslope) was quite complex, where the linear slope derived from the data showed large between-participant variability, as well as large between-participant variability in the quality of the linear relationship. The latter is the likely reason why a significant relationship was not found with sprint running. PkT180kg however showed exceptional significance against all measures. Alexander (2) identified significant correlations with peak concentric torque and sprint performance, although the authors did not account for body mass. Thorstensson et al. (21) measured force-velocity relationships in human skeletal muscle, establishing a significant relationship between the distribution of FT fibers and peak torque at 180^{o}/s ($p<0.01$). Based on these findings, individuals with more FT muscle may generate more torque during knee extension compared to those with more ST, since 180^{0}/s is a moderately fast speed. This is of course speculation, as no measures of fibre type were taken in the study.

We can assume the results from the model highlight the performance similarities between running and cycling. That is, high peak power and cadence achieved under load both require large power outputs at all velocities and large amounts of contractile RFD in a short amount of time; much like sprint running, though force is created via ground impulse rather than pedal frequency. Chelly et al. (8) reported similar results – peak watts significantly related to the initial step ($p<0.05$) and first 5m ($p<0.01$), with no significance identified when body mass was accounted for. The sex variance could be due to male and female differences such as body size/mass, technique, hip angles, and other anthropometric measures. A study by Perez-Gomez et al. (19) discovered the main factor accounting for sex differences in peak and mean power output during cycling was lower extremity muscle mass, which only partially explained the sex variance in sprint running. Many anthropometric differences between sexs are well documented, and much of these become attributing factors during running performance (13, 16). It is most likely then the between sex variance in sprint running performance and cycling was due to lower limb anthropometric differences and muscle mass, respectively. Although no significant evidence regarding fiber type expression differences between sexs currently exists, the variances identified from pkWkg and pkcRFDkg may be due predominantly to muscle fiber type expression (3, 20). From this, we can concur there is a meaningful role played out by contractile measures on sprint performance not accounted for in the Wingate. In addition to the modified Wingate, tests of contractile RFD may be the most beneficial as predictors of sprint running performance

Future research should compare the predictive ability of the current assessments with the predictability of muscle fibre typing. Fibre typing may still be the superior test despite the practicality and non-invasiveness of the assessments utilized in the current study.

The main findings show that the assessments of pkWkg and pkRPM, both performance measures from the modified Wingate test, have the most relevance to sprint performance despite the modality difference. Significant relationships between pkcRFDkg and five sprint measures were identified; which supports previous research (24). PkT180kg showed significant relationships to all sprint running measures. IsoRFD also indicated significant correlations with sprint running performance; supporting previous evidence of the relationship between dynamic movements and isometric force production (23). Further, it was noted that the independent performance components most relevant to the dependant variable of 10-20m sprint running performance included pkWkg, sex, and pkcRFDkg, together accounting for over 85% of sprint running performance. In summary, the major findings from the study indicate a relationship between performance characteristics measured during cycle ergometry and sprint running. While results may cause speculation for fibre type classification in whole muscle, no objective measures were taken in this study and thus further research in required.

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