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1 Maximum Voluntary Isometric Torque Production for Task specific and Single-  
2 joint Muscle groups and their Relation to Peak Power Output in Sprint Cycling.

3

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22 Key Words: Maximal Power; Maximum Torque; Maximal Strength; Peak Power Output; Sprint  
23 Cycling

24

25 **ABSTRACT**

26 From a cycling paradigm, little has been done to understand the relationships between maximal  
27 isometric strength of different single joint lower body muscle groups and their relation with, and  
28 ability to predict PPO and how they compare to an isometric cycling specific task. The aim of this  
29 study was to establish relationships between maximal voluntary torque production from isometric  
30 single-joint and cycling specific tasks and assess their ability to predict PPO. Twenty male trained  
31 cyclists participated in this study. Peak torque was measured by performing maximum voluntary  
32 contractions (MVC) of knee extensors, knee flexors, dorsi flexors and hip extensors whilst  
33 instrumented cranks measured isometric peak torque from MVC when participants were in their  
34 cycling specific position (ISOCYC). A stepwise regression showed that peak torque of the knee  
35 extensors was the only significant predictor of PPO when using SJD and accounted for 47% of the  
36 variance. However, when compared to ISOCYC, the only significant predictor of PPO was ISOCYC,  
37 which accounted for 77% of the variance. This suggests that peak torque of the knee extensors was  
38 the best single-joint predictor of PPO in sprint cycling. Furthermore, a stronger prediction can be  
39 made from a task specific isometric task.

40

## 41 INTRODUCTION

42 First described by Hill in 1938, mechanical power produced by muscle is the consequence of force  
43 production and shortening velocity (Hill, 1938). These two variables share a hyperbolic, inverse  
44 relationship with peak concentric mechanical power being achieved at approximately a third of  
45 maximal shortening velocity and maximum concentric force (Edman, 1979). From an applied  
46 perspective, maximal power output acts as one of the main physiological determinants and predictors  
47 of performance in sports such as running (Bundle and Weyand, 2012; Weyand et al., 2006), rowing  
48 (Ingham et al., 2002) and jumping (Ferretti et al., 1994; Grassi et al., 1991). Similarly, from a sprint  
49 cycling perspective, mechanical peak power output (PPO) at the crank level acts as a primary  
50 physiological determinant of performance. (Dorel et al., 2005; Martin et al., 2006, 2007)

51 Torque (cycling equivalent of force) and cadence (cycling equivalent of shortening velocity) are  
52 inversely related, however, unlike the descriptions of Hill, they are linearly, not hyperbolically related  
53 (Driss et al., 2002; Driss and Vandewalle, 2013; Gardner et al., 2007; Jaafar et al., 2015; Martin et al.,  
54 1997). As such, PPO is achieved at approximately half of the maximum extrapolated torque ( $T_{max}$ )  
55 and maximum extrapolated cadence ( $C_{max}$ ) (Dorel et al., 2005; Gardner et al., 2007), which is reported  
56 to occur ~120 rpm (Samozino et al., 2007); however, conceptually an increase in  $T_{max}$  and/or  $C_{max}$   
57 could result in an increased PPO, and by inference, performance.

58 To date, evidence to suggest what physiologically underpins PPO and sprint cycling performance is  
59 limited to thigh volume (Dorel et al., 2005). Other studies have used non-sporting populations to  
60 significantly correlate fat free mass (Duché et al., 2002) and isometric quadriceps strength (Driss et  
61 al., 2002). Despite Driss et al. (2002) and colleagues reporting strong correlations between maximal  
62 voluntary contractions (MVCs) during isometric knee extension in relation to both  $T_{max}$  ( $r = 0.73$ ) and  
63 PPO ( $r = 0.75$ ) in sprint cycling, there seems to be a plethora of data associating isometric MVCs with  
64 dynamic performance providing varied results. Typically correlations range between 0.3 and 0.6,  
65 whilst perhaps unsurprisingly, much stronger relationships have been observed ( $r = 0.76 - 0.97$ ) when  
66 the isometric MVC has a great degree of specificity to the dynamic performance task (for review see  
67 (Wilson and Murphy, 1996)). Typically, non-specific tasks that isolate single-joint muscle groups

78 have been used to determine performance, but these are of limited use given the performance action is  
79 often very different to the surrogate measure, therefore a task specific measure would be conceptually  
80 better (Wilson and Murphy, 1996). This is exemplified in using maximum isometric force in a bench  
81 press test to predict performance in shotput throwers where a poor relationship was observed ( $r =$   
82  $0.22$ ) as the isometric task lacked specificity to the ‘dynamic’ performance measure. Notwithstanding,  
83 maximum isometric force was strongly correlated with (dynamic) bench press 1RM ( $r = 0.78$ ) due to  
84 the performance and isometric task being very similar (Murphy et al., 1994), which further illustrates  
85 the issue of task specificity.

86 The limitation of the study carried out by Driss et al. (2002) was that it was limited to the knee  
87 extensors only, whereas sprint cycling is a compound movement and uses all major muscle groups in  
88 the lower limbs to produce impulse (Dorel et al., 2012). Consequently, it is important to investigate,  
89 and therefore gain, greater understandings of whether other muscle groups (beyond knee extensors)  
90 contribute to PPO and sprint cycling performance.

91 The implications of this study can be used to provide athletes, coaches and practitioners an evidence-  
92 based strength testing battery which can be used to monitor and predict sprint cycling performance.  
93 Further, investigating a cycling specific isometric task will in comparison to single joint will give a  
94 better idea to see if non-specific cycling strength vs. cycling specific cycling strength in relation to  
95 performance.

96 The aims of this study were two-fold. Firstly, we examined the yet untested relationship of maximal  
97 strength of the major lower body cycling muscles using isometric single-joint dynamometry and  
98 whether any can be used to predict PPO. Secondly, we assessed whether an isometric cycling-specific  
99 task would be a better predictor of sprint cycling performance than isolated isometric single-joint  
100 muscle group tasks.

## 91 **METHODS**

### 92 **Participants**

93 Twenty male cyclists volunteered to take part in the study (mean  $\pm$  SD age,  $27 \pm 5$  yr; stature,  $183.1 \pm$   
94  $8.4$  cm; mass,  $84.5 \pm 11.1$  kg). Cycling training experience and rider category varied throughout the  
95 participants, but all were engaged between 5-24 h of training per week and were regularly competing  
96 in various disciplines from sprint track to road endurance cycling from British Cycling's 'Category 3'  
97 up to the 'Elite category' national level riders. The cyclists were free from injury as assessed by a  
98 health screening questionnaire. Following institutional ethics committee approval, cyclists provided  
99 written, informed consent prior to any experimental procedures.

## 100 **Study Overview**

101 Participants attended two familiarisation sessions prior to the two experimental sessions. All lab  
102 sessions were identical whereby participants completed the same protocol on each lab visit. Lab visits  
103 were separated by at least 1 and not more than 7 d. Cyclists were asked to report to the laboratory in a  
104 hydrated state and to avoid caffeine and food for 3 h prior to testing and to avoid intense exercise in  
105 the 24 h before each session. Firstly, the participants performed isolated, isometric, single-joint MVCs  
106 with four different muscle groups (knee extensors, knee flexors, hip extensors and plantar flexion) on  
107 a dynamometer. Subsequently, after 15 minutes of passive rest, participants performed a series of  
108 cycling-specific, multi-joint isometric MVCs on an instrumented, custom made cycling ergometer.  
109 Lastly, a maximum isokinetic power-cadence protocol was performed to measure PPO.

## 110 **Isometric Dynamometry**

111 Each laboratory session started with participants performing isometric MVCs on a calibrated  
112 dynamometer (Biodex, System 4 Pro, New York, USA). Participants performed MVCs on four  
113 different muscle groups on each leg (always starting on the right side) before proceeding to the next  
114 muscle group, in the following order: plantar extensors (calf), hip extensors (gluteal), knee extensors  
115 (quadriceps) and knee flexors (hamstrings).

116 After five, 3 s sub-maximal contractions of progressing intensity, participants performed three, 3 s  
117 MVCs which were separated by 60 s of rest. The subjects were asked to maximally contract "as hard  
118 as possible" to ensure that maximal torque was achieved within the 3s. The isometric joint angles



119 were fixed at what has previously been reported as optimal torque producing angles: hip ( $45^{\circ}$ ), knee  
120 ( $70^{\circ}$  in extension and  $50^{\circ}$  in flexion) and ankle ( $0^{\circ}$ ) (Dorel et al., 2012; Ericson, 1986; Rouffet and  
121 Hautier, 2008). Specific dynamometer positions were recorded for each participant during the first  
122 familiarisation session and replicated thereafter. Between each set of MVCs (between each leg and  
123 muscle group), participants were given 5 minutes passive rest.

#### 124 **Cycling Specific Isometric Protocol (ISOCYC)**

125 Participants performed the multi-joint cycling specific isometric (ISOCYC) MVCs on a custom made  
126 cycling ergometer (BAE Systems, London, UK), which was modified to allow for isometric efforts by  
127 attaching a clamp to the flywheel. The ergometer was set up to replicate the participants' cycling  
128 position whilst using their own cycling shoes and pedals. The participants performed the ISOCYC  
129 MVCs in the saddle and were instructed to remain seated throughout. To further ensure that they  
130 remained seated, they were strapped into the saddle using a webbing seatbelt, secured and tightened  
131 around their waist and ergometer whilst their forearms were positioned on the crossbar of the  
132 handlebars. The drive-side (right) crank arm was positioned at  $90^{\circ}$  from top, dead centre (TDC) using  
133 an inclinometer. As with the dynamometer, the participants were given three sub-maximal efforts at  
134 what they perceived at 60%, 70% and 80% of their perceived MVC. Prior to performing the ISOCYC  
135 efforts, participants were reminded to 'try to pedal the cranks forward as hard as possible using both  
136 legs' (i.e., the right leg pushing down and the left leg pulling up, simultaneously). Following a 3 s  
137 countdown, participants performed a 3 s MVC, which was performed 3 times with 60 s rests in  
138 between efforts. After 5 minutes passive rest, the process was then repeated with the only difference  
139 being the drive side (right) and non-drive side (left) crank positions being reversed. The ergometer  
140 was fitted with instrumented cranks (170 mm) that following calibration, measured cumulative, as  
141 well as individual, right and left crank arm torque production (Factor Cranks, BF1 Systems, Diss, UK)  
142 at a sampling rate of 200 Hz.

#### 143 **Isokinetic Peak Power Output Protocol**

144 Prior to performing the maximal isokinetic efforts to determine PPO, participants undertook a  
145 standard 10-minute warm-up of submaximal cycling at a self-selected intensity (between 100-150 W)  
146 and cadence (between 80-90 RPM). For the maximal isokinetic efforts, participants performed 4 s  
147 sprints at 60, 110, 120, 130 and 180 RPM. Cadences were randomised for all laboratory sessions  
148 (www.random.org). Prior to each effort, the motor was brought up to the desired velocity and  
149 participants were instructed to pedal below the pre-set cadence and reminded to ‘attack the effort as  
150 fast and as hard as possible’ once the effort began. The investigator gave a 3 s countdown and the  
151 participants performed a 4 s maximal effort against the set cadence. A period of 3 minutes passive rest  
152 was given between each isokinetic sprint. As with the ISOCYC, participants used their own cycling  
153 shoes and pedals and performed the PPO protocol on ergometer, which was identically set-up to their  
154 racing positions. All efforts were performed in the saddle with each cyclist using the ‘drop’  
155 handlebars.

## 156 **Data Processing**

157 Torque from the dynamometer was sampled (2,000 Hz) and fed directly into a data acquisition system  
158 (Micro 1401, CED, Cambridge, United Kingdom) and the accompanying PC utilizing Spike2  
159 software (CED, Cambridge, United Kingdom). Of the three MVCs, the highest peak torque value  
160 (from the isometric dynamometry) for each individual muscle group was recorded. As the  
161 performance task (sprint cycling) uses both limbs, peak torque values were averaged for both right  
162 and left muscle groups for each experimental session and then averaged again over both experimental  
163 sessions. Likewise, peak torque values from right and left cranks in all ISOCYC efforts were  
164 extracted and averaged for both sessions and then averaged between sessions.

165 For both ISOCYC and PPO efforts, data was being recorded wirelessly on to an electronic measuring  
166 system (BF1 Systems, Diss, United Kingdom). Subsequent to each lab session, the raw data was  
167 exported into Spike2, where power and cadence was calculated using custom made scripts. For the  
168 isokinetic PPO sprints, the first three full revolutions (from TDC to TDC) of each effort at the pre-  
169 determined cadence were recorded and analysed; the revolution with the highest mean torque (and

170 therefore, power) was used. For each participant, the revolution analysed for each cadence was  
171 averaged between sessions. Then, the five power outputs at each pre-determined cadences, a quadratic  
172 regression power-cadence relationship was plotted and PPO was interpolated at the apex of the curve.

### 173 **Statistical Analysis**

174 The relationship between PPO and peak torques for different muscle groups in isometric  
175 dynamometry MVCs and the ISOCYC were calculated by using a Pearson's product moment  
176 correlation. Pearson's correlation coefficients were defined as previously described by Buchheit and  
177 colleagues: trivial (0.0), small (0.1), moderate (0.3), strong (0.5), very strong (0.7), nearly perfect  
178 (0.9), and perfect (1.0) (Buchheit et al., 2010). Any correlation greater than  $r = 0.50$  was used in a  
179 step-wise linear regression to predict PPO from peak torque values from isometric dynamometry of  
180 relevant muscle groups. If any were seen as significant predictors, they were placed into another step-  
181 wise linear regression against ISOCYC to determine whether a more task specific or a non-skilled  
182 task best predicts PPO. All statistics was performed on SPSS (IBM Corp., Armonk, N.Y., USA) and  
183 reported as mean (SD) unless otherwise stated.

### 184 **RESULTS**

185 Average mechanical PPO was measured at  $1197 \pm 215$  W (Figure 1). In relation to PPO, maximum  
186 isometric strength of the knee extensors showed a very strong relationship ( $r = 0.71$ ;  $p < 0.01$ ). Strong  
187 relationships were also observed between the knee flexors ( $r = 0.53$ ;  $p = 0.02$ ), the hip extensors ( $r =$   
188  $0.56$ ;  $p = 0.01$ ) and PPO with a trivial, non-significant relationship between ankle extensors and PPO  
189 ( $r = -0.03$ ;  $p = 0.89$ ). The relationship between PPO and ISOCYC (Figure 2) had a very strong  
190 relationship ( $r = 0.87$ ;  $p < 0.01$ ).

191 All isometric dynamometry muscle groups that were assessed (apart from the plantar extensors) were  
192 entered into a step-wise regression model and significantly predicted PPO ( $F_{(3, 19)} = 16.06$ ,  $p = 0.001$ ,  
193  $R^2 = 0.47$ ). However, only peak torque from isometric knee extension contributed significantly to the  
194 prediction, which accounted for 47% of the variation in PPO ( $p = 0.001$ ). Knee flexion ( $p = 0.460$ )  
195 and hip extension ( $p = 0.507$ ) did not contribute meaningfully to the prediction. Accordingly, peak

196 torques of knee extensors and ISOCYC were put into a subsequent step-wise regression model and  
197 PPO was significantly predicted ( $F_{(2, 19)} = 23.55$ ,  $p < 0.001$ ,  $R^2 = 0.77$ ). Only peak isometric torque  
198 from ISOCYC added statistical significance to the prediction, which accounted for 77% of the  
199 variation ( $p = 0.001$ ). Knee extension did not contribute significantly to the relationship ( $p = 0.389$ ).

## 200 **DISCUSSION**

201 The purpose of this study was two-fold. Firstly, to establish whether maximal torque produced from  
202 single joint isometric dynamometry can significantly predict PPO in sprint cycling. Secondly, how  
203 single joint isometric dynamometry compares to a cycling specific isometric task in predicting PPO.  
204 With respect to the first aim, of all the major lower body muscle groups that were assessed using  
205 isometric single joint MVC, peak torque produced by the knee extensors was shown to be a  
206 significant predictor of PPO. However, with respect to the second aim, when peak torque from the  
207 knee extensors was compared to peak torque produced by ISOCYC, it was the cycling specific  
208 measure of maximal strength that was shown to be the only significant predictor of PPO.

209 With ISOCYC being the best predictor of PPO and therefore, the potential to predict sprint cycling  
210 performance, it builds on the growing body of evidence that task specific isometric contractions are a  
211 better predictor of performance than non-skilled, single-joint tasks, like isometric dynamometry. The  
212 ISOCYC is easy to perform, is a more familiar task to trained cyclists and in comparison to  
213 dynamometry is significantly cheaper. Furthermore, should the instrumented cranks be on their own  
214 bike, it can be performed almost anywhere. The disadvantage of using an isometric compound  
215 movement, like ISOCYC, to an isolated single joint MVC, is that it does not provide sufficient  
216 information to ascertain which muscle groups are responsible for any changes that may be observed.

217 Previously, instrumented cranks have been able to provide power-cadence (and torque-cadence)  
218 relationships as an accurate means to model cycling performance in the laboratory which is reflected  
219 in field performances (Gardner et al., 2007). However, though this may be thought of as a more  
220 ecologically valid task, it involves a large technical/biomechanical component that makes it hard to  
221 quantify true physiological changes in strength of muscle group(s). Isometric tasks (single-joint

222 dynamometry (in this case, knee extensor assessment) can provide valuable information of strength  
223 changes in targeted muscle groups. This means that it can act as an abstract measure of strength that is  
224 far removed from the task, can be monitored by coaches and practitioners to provide information on  
225 meaningful changes in physiological strength relative to a key performance measure as well as  
226 provide valuable feedback on the efficacy of previous training or indeed inform the prescription and  
227 monitoring of future training programming.

228 The findings from the single joint dynamometry concur with previous work (Driss et al., 2002) that  
229 showed a similar, strong relationship between isometric MVC of the knee extensor and PPO. The hip  
230 extensors and knee flexors displayed large and significant relationships to PPO and but they did not  
231 significantly add to the regression model that already included the knee extensors. No relationship  
232 between maximal plantar flexor strength with PPO was observed which is contrary to the high  
233 muscle activation levels of the plantar flexors during maximal sprint cycling (Dorel et al., 2012). A  
234 possible explanation for this finding could either that plantar flexor strength may be more cycling/task  
235 specific rather than a general, non-specific, abstract strength measure and/or may provide some  
236 evidence that the planar flexors are involved in the transfer of mechanical energy from the proximal  
237 muscles to the crank (Raasch et al., 1997).

238 A plausible suggestion for why knee extensors are the only significant single joint predictors of PPO  
239 could be because the superficial mono-articular muscles of the quadriceps (i.e. VM and VL) are  
240 maximally activated when peak torque is achieved around the crank cycle (Dorel et al., 2012). Thus,  
241 stronger knee extensors are critical for high instantaneous torque and therefore, PPO. Nevertheless,  
242 irrespective of why the knee extensors are the best predictor of PPO, peak torque from ISOCYC  
243 MVCs provides a task specific, less time consuming, cheaper method to predict PPO that is easy to  
244 administer and can be used by athletes, coaches and practitioners to monitor changes in PPO and  
245 therefore make some inference about performance.

246 There are limitations to this study that should be mentioned. Firstly, it is recommended that at least 50  
247 participants are used when employing a multiple linear regression in comparison to the 20 used in this

248 study (Green, 1991). In addition, not all the major muscle groups were assessed. Two major lower  
249 body muscle groups: hip flexors and dorsiflexors were not assessed which have been shown to be  
250 maximally active during sprint cycling (Dorel et al., 2012) and no upper body measures which have  
251 been shown to contribute to high intensity cycling even though it is sub-maximal (Grant et al., 2015).

252 In conclusion, of all the major lower body muscle groups, peak torque in the knee extensors from  
253 isometric dynamometry was the best predictor of peak power output in sprint cycling. Moreover, our  
254 data show that a stronger prediction of sprint cycling performance can be made from a measure of  
255 maximal torque that is performed in an isometric cycling specific task to indirectly assess PPO. This  
256 provides a cheaper, easier and more applicable method for athletes, coaches and practitioners to  
257 monitor surrogate measures of sprint cycling performance.

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## 261 **CONFLICTS OF INTEREST**

262 The authors do not have any conflicts of interest.

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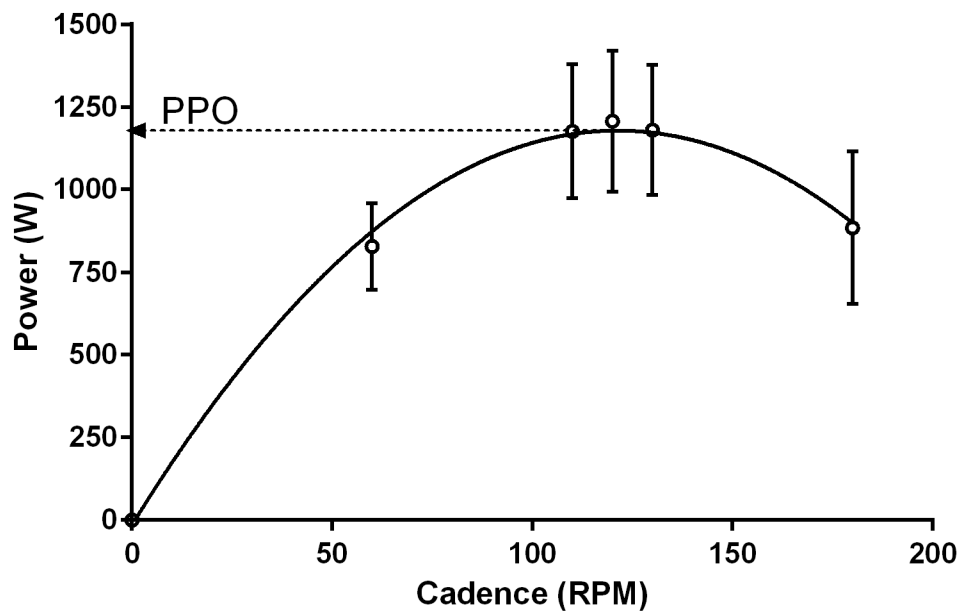
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333 Figure 1.

334 Figure 1: Power-cadence relationship of second order polynomial was formed after performing  
335 maximal sprints at 60, 110, 120, 130 and 180 RPM;  $R^2 = 0.996$ ;  $y = -0.081x^2 + 19.35x - 13.96$ ;  
336 Mechanical peak power output (PPO) was interpolated and measured at  $1108 \pm 215$  W.

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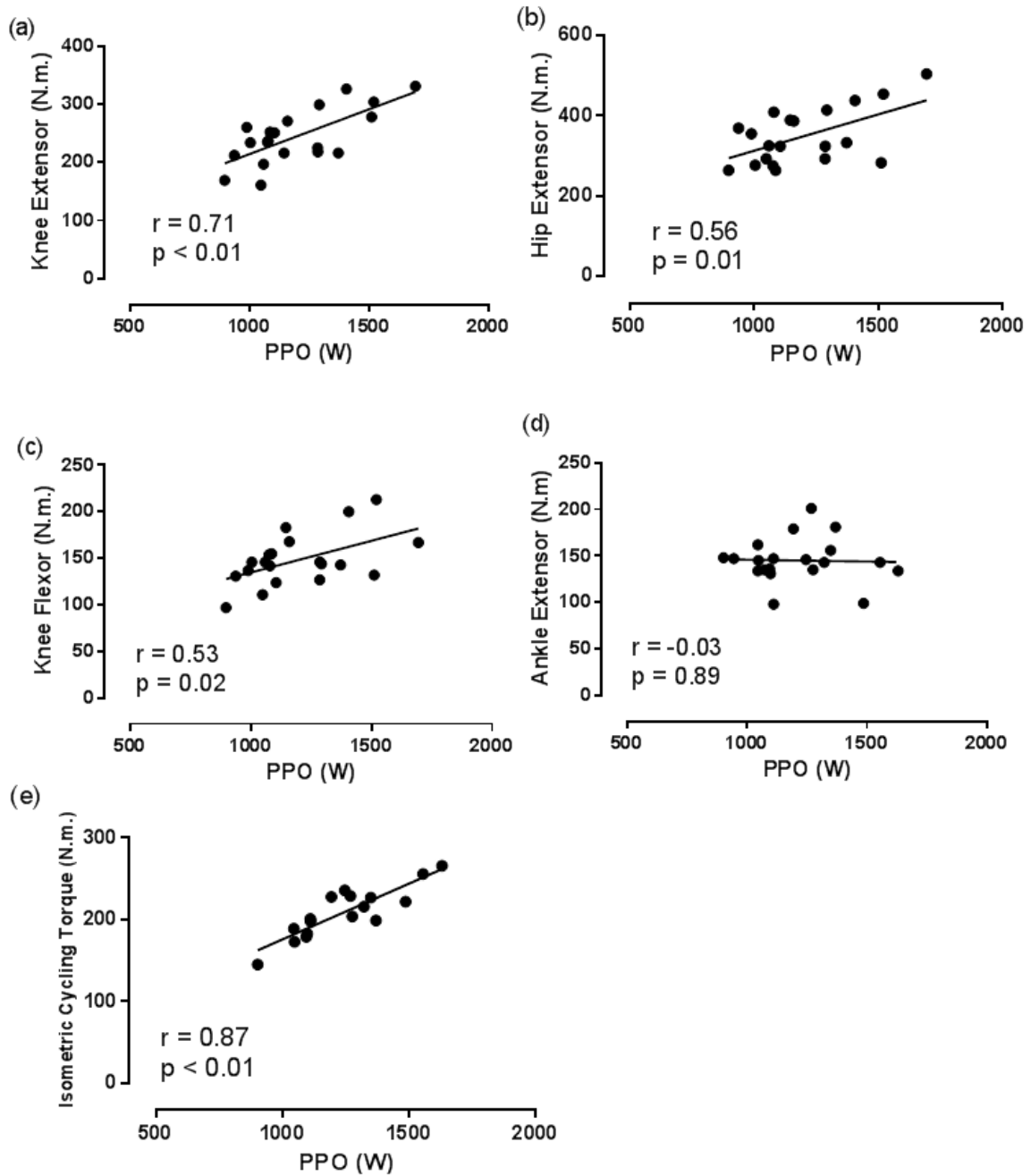
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340 Figure 2

341 Figure 2: Relationship between (a) peak isometric strength of knee extensors and mechanical peak  
342 power output (PPO) (b) peak isometric strength of hip extensors and PPO (c) peak isometric strength  
343 of knee flexors and PPO (d) peak isometric strength of ankle extensors and PPO (e) peak isometric  
344 cycling specific torque and PPO.



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