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

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

ABSTRACT

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

INTRODUCTION

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

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

To date, evidence to suggest what physiologically underpins PPO and sprint cycling performance is limited to thigh volume (Dorel et al., 2005). Other studies have used non-sporting populations to significantly correlate fat free mass (Duché et al., 2002) and isometric quadriceps strength (Driss et al., 2002). Despite Driss et al. (2002) and colleagues reporting strong correlations between maximal voluntary contractions (MVCs) during isometric knee extension in relation to both T_{max} ($r = 0.73$) and PPO ($r = 0.75$) in sprint cycling, there seems to be a plethora of data associating isometric MVCs with dynamic performance providing varied results. Typically correlations range between 0.3 and 0.6, whilst perhaps unsurprisingly, much stronger relationships have been observed ($r = 0.76 – 0.97$) when the isometric MVC has a great degree of specificity to the dynamic performance task (for review see (Wilson and Murphy, 1996)). Typically, non-specific tasks that isolate single-joint muscle groups have been used to determine performance, but these are of limited use given the performance action is often very different to the surrogate measure, therefore a task specific measure would be conceptually better (Wilson and Murphy, 1996). This is exemplified in using maximum isometric force in a bench press test to predict performance in shotput throwers where a poor relationship was observed (r = 0.22) as the isometric task lacked specificity to the 'dynamic' performance measure. Notwithstanding, maximum isometric force was strongly correlated with (dynamic) bench press 1RM (r = 0.78) due to the performance and isometric task being very similar (Murphy et al., 1994), which further illustrates the issue of task specificity.

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

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

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

METHODS

Participants

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

Study Overview

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

Isometric Dynamometry

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

After five, 3 s sub-maximal contractions of progressing intensity, participants performed three, 3 s MVCs which were separated by 60 s of rest. The subjects were asked to maximally contract "as hard as possible" to ensure that maximal torque was achieved within the 3s. The isometric joint angles were fixed at what has previously been reported as optimal torque producing angles: hip (45^o), knee (70^o in extension and 50^o in flexion) and ankle (0^o) (Dorel et al., 2012; Ericson, 1986; Rouffet and Hautier, 2008). Specific dynamometer positions were recorded for each participant during the first familiarisation session and replicated thereafter. Between each set of MVCs (between each leg and muscle group), participants were given 5 minutes passive rest.

Cycling Specific Isometric Protocol (ISOCYC)

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

Isokinetic Peak Power Output Protocol

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

Data Processing

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

For both ISOCYC and PPO efforts, data was being recorded wirelessly on to an electronic measuring system (BF1 Systems, Diss, United Kingdom). Subsequent to each lab session, the raw data was exported into Spike2, where power and cadence was calculated using custom made scripts. For the isokinetic PPO sprints, the first three full revolutions (from TDC to TDC) of each effort at the pre-determined cadence were recorded and analysed; the revolution with the highest mean torque (and therefore, power) was used. For each participant, the revolution analysed for each cadence was averaged between sessions. Then, the five power outputs at each pre-determined cadences, a quadratic regression power-cadence relationship was plotted and PPO was interpolated at the apex of the curve.

Statistical Analysis

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

RESULTS

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

All isometric dynamometry muscle groups that were assessed (apart from the plantar extensors) were entered into a step-wise regression model and significantly predicted PPO ($F_{(3, 19)} = 16.06$, $p = 0.001$, $R^2 = 0.47$). However, only peak torque from isometric knee extension contributed significantly to the prediction, which accounted for 47% of the variation in PPO ($p = 0.001$). Knee flexion ($p = 0.460$) and hip extension ($p = 0.507$) did not contribute meaningfully to the prediction. Accordingly, peak torques of knee extensors and ISOCYC were put into a subsequent step-wise regression model and PPO was significantly predicted ($F_{(2, 19)} = 23.55$, $p < 0.001$, $R^2 = 0.77$). Only peak isometric torque from ISOCYC added statistical significance to the prediction, which accounted for 77% of the variation ($p = 0.001$). Knee extension did not contribute significantly to the relationship ($p = 0.389$).

DISCUSSION

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

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

Previously, instrumented cranks have been able to provide power-cadence (and torque-cadence) relationships as an accurate means to model cycling performance in the laboratory which is reflected in field performances (Gardner et al., 2007). However, though this may be thought of as a more ecologically valid task, it involves a large technical/biomechanical component that makes it hard to quantify true physiological changes in strength of muscle group(s). Isometric tasks (single-joint dynamometry (in this case, knee extensor assessment) can provide valuable information of strength changes in targeted muscle groups. This means that it can act as an abstract measure of strength that is far removed from the task, can be monitored by coaches and practitioners to provide information on meaningful changes in physiological strength relative to a key performance measure as well as provide valuable feedback on the efficacy of previous training or indeed inform the prescription and monitoring of future training programming.

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

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

There are limitations to this study that should be mentioned. Firstly, it is recommended that at least 50 participants are used when employing a multiple linear regression in comparison to the 20 used in this study (Green, 1991). In addition, not all the major muscle groups were assessed. Two major lower body muscle groups: hip flexors and dorsiflexors were not assessed which have been shown to be maximally active during sprint cycling (Dorel et al., 2012) and no upper body measures which have been shown to contribute to high intensity cycling even though it is sub-maximal (Grant et al., 2015).

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

ACKNOWLEDGEMENTS

The authors would like to thank the participants who volunteered their time for this study. This is contribution number 189 from the NWU-Water Research Group.

CONFLICTS OF INTEREST

The authors do not have any conflicts of interest.

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Figue 1.

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

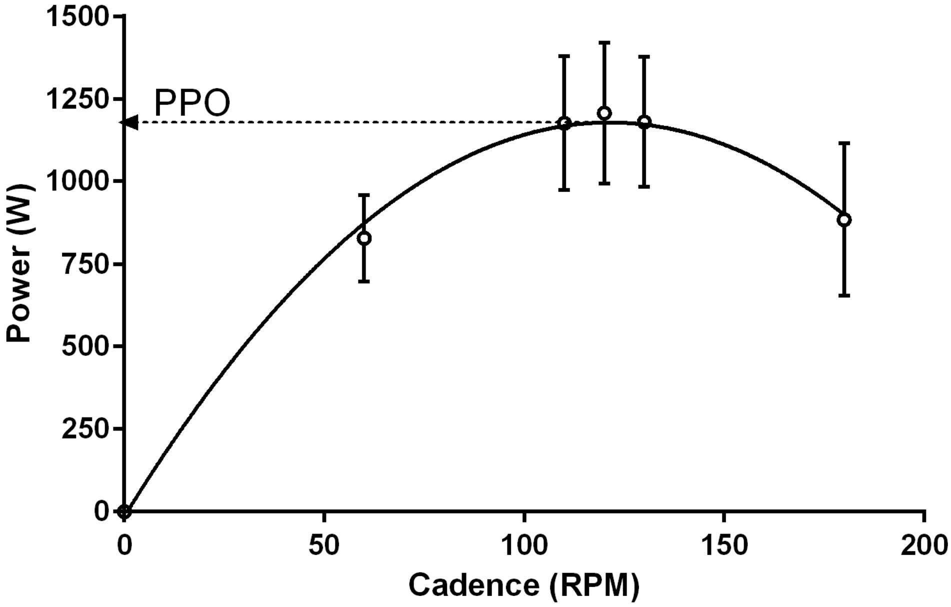

Figure 2

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