SPECIAL INVITED PAPER

THE POWER OF CYCLING

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Abstract

One of the advantages of cycling exercise is that the rider is interfaced to a machine, and this exercise can be easily metered. Recent technological advances have made this metering easier and cheaper such that riders, sports scientists and coaches are able to record the external work done, and thus the net rate of mechanical work (power) during training and racing. Since external power is related to performance, the power requirements of competition can be observed and the training intensity can be prescribed. However, the ability to closely scrutinize power during training brings about a number of issues which need to be addressed. These issues include the accuracy and reliability of the meter, the relationship of the external work rate to the total physiological stress, and how training prescription through analysis by power may change the athlete-coach relationship.

Keywords: Cycling, performance, power

Introduction

The main attraction of cycling for exercise scientists is that it is a mode of exercise which can be easily metered in the laboratory through measurements of parameters such as cadence, torque and power output in a controlled environment. In addition, the workload can be fixed through the use of electronically braked cycling ergometers and therefore, the rider must produce a set mechanical power outputs that are independent of cadence or torque. For these reasons, many interventions, ranging from nutrition to training and pharmacology, have been tested to determine their effect on the response of cycling exercise.

This ‘attraction’ has resulted in a thorough physiological understanding of the human ‘machine’ as it pedals, mostly in the laboratory setting, but increasingly in the field. This combined with the money associated with success in professional cycling and the fact that it is a long-time Olympic sport means that cycling is one of the most studied sports in the world. These data, along with those available in the public domain, provide interesting discussions that absorb many pages, both on paper and on the Web.

However, such data require careful interpretation in order to be useful and careful interpretation requires specific knowledge. Hence, the purpose of this article is to address the current trends of measuring power output in cycling and discuss its advantages, disadvantages and utility.

Measuring power

Recent technological advances in strain-gauge design, battery life and portable telemetrics have made measurements of cycling power output possible in the field. Indeed, many cyclists and coaches now rely on the power measured in the drivetrain as a means of judging and prescribing effort. This has spawned an industry in online data interpretation tools aligned with coaching tips and cycling science advice. The data from individual athletes on known sections of terrain have even produced a number of online ‘competitions’ such as Strava®, whereby the cyclists can compete at their own leisure or with their selected group rather than competing at the same time in the traditional race format. This can be done by comparing their power and speed data for a known section of the terrain.

The most commonly available appliances for measuring power are ‘power’ cranks. In power cranks, strain gauges are placed between the bottom bracket and chain rings to provide a net torque measure, in which cadence is recorded separately from either a magnet-based cadence sensor or more recently, an accelerometer in the crank arm. A ‘head’ or display/data-logging device is used to collect the data, calculate power, as well as display and store this information, often alongside GPS-related data (i.e. speed, altitude and position). Once calibrated, the reliability of the well-known brands appears to be good, with a claimed accuracy of around ±2%. Power sensing (rear wheel) hubs are also available for some time and very recently, power measuring systems through torque at the pedal axle can be purchased, providing independent left-right data. Other power measuring systems can also be used (e.g. ‘power hubs’ and chain tension meters), provided that they lie within the drive chain.

Power measurements during cycling

The advent of portable telemetry for heart rate (HR) measurements around 30 years ago has made HR monitors the coaches’ preferable method for prescribing and monitoring training intensity. Training programmes are often provided by coaches to their athletes in the form of set times spent in HR ‘zones’; the latter being calculated as the percentage of maximum HR or the percentage of the HR reserve (i.e. the difference between maximum and resting HR). The astute coach, however, will understand the limitations of measuring only the cardiovascular stress as an indicator of intensity and thus, the whole body physiological stress (Stannard & Thompson, 1998). A more sensible measure might indicate the sum of all the stresses revealed by the body during cycling. This measure would relate, to some extent, to the rate of the external work done.

The fact that power (Watts) has now replaced heart rate as the coaches' 'tool' of choice to indicate training or competition workload requires some thought because each tool is measuring a different thing. As mentioned above, heart rate is an indication of the cardiovascular stress of the rider, and it is an indicator of the total (external plus internal) work rate. On the other hand, power, which is measured from the drivetrain, is a measure of the rate of external mechanical work done. The latter represents the external effect of the bicycle-rider 'system' on the road and therefore, defines the performance for a given set of environmental variables. Assuming that skill is not a limiting factor, the total physiological stress is the parameter that limits performance. The total physiological stress is the sum of the stresses of a number of physiological 'systems', whereby the relative stress of each is slightly proportionally different during each ride.

For example, during hot and humid environmental conditions, thermal and cardiovascular stresses are higher for a particular external work rate than those during cool conditions (Schlader, Stanndard, & Mundel, 2010). At the same time, activation of the Group III and Group IV muscle afferents may not be different at lower temperatures and humidity as they respond to mechanical stimuli from muscle contraction (Kniffki, Mense, & Schmidt, 1978; Hayward, Wesselmann, & Rymer, 1991) and changes in pressure in the muscle vascular bed (Haouzi, Chenuel, & Huszczuk, 2004). Similarly, the administration of stimulants such as caffeine can produce higher power outputs for the same level of perceived exertion, by decreasing the sensation of fatigue (Glade, 2010). Hence, even though measuring power at the drivetrain will indicate the leg's muscular work rate, it does not measure the sum of the physiological stresses experienced by the body. Nevertheless, the power meter might provide a reasonable correlation to the total physiological stress in most circumstances.

Internal versus external work rate

Since training in order to improve athletic performance does not affect the bicycle (rather, it only affects the physiology of the rider), it would seem more sensible to dictate workload through measurement of the physiological stress rather than power. Even though heart rate only reflects the stress of the cardiovascular system, it nevertheless provides a cheap and easy-to-measure representation of oxidative energy expenditure in thermoneutral conditions. In theory, other physiological stresses can be monitored, including thermal stress, metabolic stress and even whole body oxygen consumption. However, in reality, these measurements can only be done in the laboratory, and certainly not during cycling competitions. On the other hand, these stresses arise as a response to muscular effort which is a function of the neuromuscular system. Therefore, what becomes the best means of metering cycling intensity is not a simple and straightforward choice.

Perhaps a more sensible approach is to try to understand what adaptation is being aimed at in a particular training session and then use the appropriate means of monitoring intensity. Ideally, that would be a measure of the rate limiting physiological parameter for that aim. For example, if the maximum short-term effort (e.g. maximum second power production) is being trained, then post-reflective power monitoring is useful to compare one session to the next. If endurance is being trained, then the duration of riding is most useful, and if the environmental conditions are hot and humid, the core temperature or heart rate may be a good measure of the limiting physiological parameter.

A combination of some or all of these parameters measured during each training session can potentially provide the athlete and coach with the best means of creating optimum training programmes. In the future, perhaps a database can be developed for an individual to describe the combination of power output and its relationship with associated body stresses such as heart rate, core temperature, muscle activation level and pain. It is likely that these relationships will be very individualistic, which will require several years of training and competition for such a system to have utility.

Data overload

With this idea in mind, cyclists and coaches are currently experiencing data ‘overload’ with power measurements alone, and the addition of other variables may be difficult to interpret by anyone other than a specialist, cycling-sport scientist or physiologist. To manage the ‘reams’ of data produced during training, many coaches key in the power data from all of their athletes’ training sessions into online software programs which are claimed to be capable of directing the training volume, predict performance, and even indicate the level of fatigue direct training volume – these can all be done without ever seeing the rider! This means of automatically and remotely managing the data ignores psychological, physiological and physical signals, but turns a very complex scenario into a number of simple empirical evaluations which a rider or coach can understand.

While such practice may be appealing, there is danger that the holistic side of coaching and the coaching process is ignored (Cushion, 2007). Coaching is a process that involves dynamic social activity that engages both the coach and athlete (Cushion, Armour, & Jones, 2006; Lyle, 1999) in a journey of inter-intra personal understanding and self-fulfilment (Cushion, 2007) through process and task mastery. With this in mind, the value in number-based coaching, such as that enabled by power data, may only be apparent once the coach-athlete relationship and the human-human interaction is established prior to its use.

Accuracy and reliability of power meters

Comparison of the power data between and within individuals is only valid if the meters are accurate and reliable. A large number of cycling studies have made use of the SRM power meter for research (Cushion et al., 2006; Jowett, 2005; Johnson et al., 2003) with a manufacturer-claimed accuracy of ±2% (Johnson, Stannard, & Thompson, 2004). The main reason that this brand has been used in most studies seems to be its longevity in the marketplace rather than superior accuracy. Other power meters such as Powertap (±2.5%) and Quarq (2%) have similar claimed levels of accuracy and have been compared against the SRM power meter (Johnson et al., 2004; Macdermid & Edwards, 2010). However, these power meters are cited less often in cycling research, which may be due to the fact that they are relative newcomers in the marketplace. More recent arrivals such as the Polar 710 (Gardner et al., 2004) and the Velotron Ergometer (Gardner et al., 2004) have undergone rigorous testing to determine their usefulness and accuracy compared with devices that are currently in use.

In recent years, strain gauges in individual pedal axles (Millet, Tronche, Fuster, Bentley, & Candau, 2003), which are closer to the bicycle-rider interface than cranks, have become commercially available and provide even more data, particularly the torque produced independently by each leg. This is important because most power meters are only capable of detecting the net torque, which is the difference in the positive and negative effort produced by both legs at the same time. It has long been recognized that even elite cyclists produce negative tangential forces during upstroke (Abbiss, Quod, Levin, Martin, & Laursen, 2009; Sparks, Dove, Bridge, Midgely, & McNaughton, 2015). To maintain a given power, the other leg must compensate the negative force and power by producing a greater force and power during downstroke. The extent to which this is true can change – a recent work (Hull & Davis, 1981) has shown that with fatigue, greater negative tangential forces are seen in the upstroke, which decreases the efficiency of pedalling. A sensor that is only capable of detecting the net torque would not be able to measure changes in the resisting force, which results in misleading inferences about the physiological load experienced by the rider. In theory, these 'power pedals' are as interchangeable between bikes as the cranks. However, this is not necessarily the case since the crank-pedal interface seems important for the purpose of calibration and thus, accuracy.

One recent addition to the power meter range is a device that measures torque in one leg only. Hence, despite a claimed accuracy of ±2%, this is only for the power associated with the left leg. The overall accuracy is dependent upon the symmetry of force production between the left and right legs, and yet power asymmetries are the ones commonly seen (Soden & Adeyefa, 1979).

The accuracy of even the best devices can vary (Johnson, Stannard, Chapman, & Thompson, 2006), and it is best determined using a calibration rig. However, since the reason for reviewing power data is to understand the small changes in performance, perhaps the most important aspect is the reliability of a given device. Reliability is more a function of the regularity and reproducibility from one measurement or training session to another within the same device. The coach can make inferences from the training and racing data if the device is reliable even though it is not the most accurate device in the market. However, poor reliability can make it difficult to compare the performance between riders using different meters, and thus may undermine any Web-based comparisons between riders. Reliability may also be affected by environmental conditions, and therefore, manufacturers have begun to incorporate temperature compensation when factoring a power reading from the measured torque. It is for this reason that manufacturers also recommend mechanical zeroing to be carried out regularly by the end user.

Summary

Although the ability to measure and monitor work rate during cycling has been available for many years in the laboratory, it is only recently that technology has made this measurement widespread in the field. The data obtained, and combined with other physical and physiological measures during a ride, is changing the face of recreational and competitive cycling. However, the ability to measure and record power in training brings about a number of issues such as athlete-coach interactions, whereby the art of coaching is lost to some extent. Nevertheless, the data can be interpreted appropriately provided that they are accurate and ideally combined with other physiological and psychological measures and signs. This in turn, will help one to formulate training and racing strategies which will improve athletic performance.

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