Construction of an Isokinetic Eccentric Cycle Ergometer for Research and Training

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Eccentric cycling serves a useful exercise modality in clinical, research, and sport training settings. However, several constraints can make it difficult to use commercially available eccentric cycle ergometers. In this technical note, we describe the process by which we built an isokinetic eccentric cycle ergometer using exercise equipment modified with commonly available industrial parts. Specifically, we started with a used recumbent cycle ergometer and removed all the original parts leaving only the frame and seat. A 2.2 kW electric motor was attached to a transmission system that was then joined with the ergometer. The motor was controlled using a variable frequency drive, which allowed for control of a wide range of pedaling rates. The ergometer was also equipped with a power measurement device that quantified work, power, and pedaling rate and provided feedback to the individual performing the exercise. With these parts along with some custom fabrication, we were able to construct an isokinetic eccentric cycle ergometer suitable for research and training. This paper offers a guide for those individuals who plan to use eccentric cycle ergometry as an exercise modality and wish to construct their own ergometer.

Keywords: cycling, eccentric muscle contraction, power, multi-joint exercise

For over 50 years, researchers have been intrigued by the observation that eccentric cycling (cycle ergometry adapted to impose active muscle lengthening) can be performed at a considerably lower metabolic cost compared with traditional concentric cycling (cycle ergometry used to impose active muscle shortening).¹ This reduced metabolic cost allows an individual to perform repetitive, high-force, multijoint eccentric muscle actions at a relatively low central hemodynamic and metabolic demand,²⁻⁵ which may be particularly important in patient and athletic populations. Indeed, several previous authors have demonstrated that chronic eccentric cycling (6-12 weeks) is a potent stimulus for improving locomotor muscle function in a variety of populations that include: patients with Parkinson’s disease,⁶,⁷ cancer survivors,⁸ total knee arthroplasty patients,⁹,¹⁰ individuals with anterior cruciate ligament injuries,¹¹⁻¹³ elderly individuals,¹⁴,¹⁵ young healthy individuals,¹⁶⁻²⁰ and athletes.²¹,²² Results from these investigations demonstrate the efficacy of eccentric cycling and might induce many other researchers to adopt eccentric cycling as a model for exercise interventions. However, potential barriers such as the limited number of commercially available eccentric cycle ergometers, manufacture constraints (eg, maximum work rate < 200 W), and substantial cost may impede the use of eccentric cycling.

The limitations noted above could be circumvented by constructing an eccentric cycle ergometer in-house. In fact, previous authors²³⁻²⁵ have briefly described the components used to build an eccentric cycle ergometer. These early ergometers, however, were constructed using mostly custom parts that resulted in rather complex and costly designs. With advancements in technology, commonly available parts could be used to construct a modern eccentric cycle ergometer to be used in clinical, research, and sport training settings. In our laboratory, we have used eccentric cycling in several recent studies¹⁶,²⁶⁻²⁸ and the ergometer we currently use for training¹⁶ (Figure 1) was built using exercise equipment, industrial parts, and a modest amount of custom fabrication. The purpose of this technical note is to describe the process by which we built an isokinetic eccentric cycle ergometer, discuss the problems we encountered, solutions we devised, and potential limitations of our system.

Methods

Ergometer Frame

While one could build the ergometer frame and seat system, we chose to use a commercial quality recumbent cycle ergometer (LifeFitness, LifeStyle 9100, Brunswick Corp., Lake Forest, IL, USA). These can be purchased...
new but we obtained a used unit from our university surplus and salvage for a fraction of the original price. Other options for obtaining a used frame system at a low cost include online classified advertisements where used exercise equipment is readily available. We selected an ergometer with a recumbent seat system as this position allows for greater torso stabilization compared with a normal upright cycling position. An important aspect of the seat adjustment mechanism is that it has locking stops. Our first eccentric cycle ergometer used a simple friction lock and this often slipped due to the high forces during eccentric cycling. With these considerations in mind, we removed all the parts from the ergometer, leaving the frame and seat (Figure 2A). The specific model of ergometer we purchased was equipped with a “one piece” style crank which would not allow us to use the power meter (described below) which requires a standard crank axle (“bottom bracket”). Consequently, we modified the ergometer by welding a standard bottom bracket shell inside the larger original shell for the one piece crank. These bottom bracket shells can be obtained from bicycle frame building supply shops such as Nova Cycles Supply (http://www.cycle-frames.com/bicycle-frame-tubing).

Motor and Speed Controller

We used a 3450 rpm, 2.2 kW, three-phase electric motor (Delta International Machinery Corp., Pittsburgh, PA, USA) to power the ergometer (Figure 2B). This motor is controlled using a TECO FM50 variable frequency drive (VFD, TECO/Westinghouse, Round Rock, TX, USA) which allows control of electrical signal frequency and thereby control of motor speed and pedaling rate (Figure
2C). Thus, the ergometer functions in an adjustable, isokinetic mode. Note that in our current configuration there is only one on/off switch. It is located on the VFD right in front of the individual and is easily accessible by the investigator who usually stands adjacent to the user. While a 2.2 kW motor might seem excessive, it is important to point out that the motor would only produce this power at full rated speed. Because we use the VFD to control pedaling rate, the motor generally runs at approximately 2/3 of the rated speed and thus only functions as a 1.5 kW motor. We could have changed our gear ratios in the transmission system (described below) so that the motor was always operating at rated speed but our current system allows more flexibility and can deliver substantial power at a broad range of pedaling rates (30–95 rpm). Finally, pedaling rate will vary slightly when the user resists the motor due to some compliance in the system (eg, ~1 rpm per 250 W). Consequently, pedaling rate should be set slightly higher than the target pedaling rate.

**Transmission System**

Our transmission system (Figure 2B) is composed of a gear reducer (Type 125 S-2 Sever Drive Systems, Dravskem polju, Slovenia) and a chain drive. The ratio of the gear reducer is 16.65:1 and its rated capacity is 5.5 kW. The output shaft of the gear reducer was fitted with an industrial #40 sprocket (17 teeth) and the power meter was also equipped with a #40 sprocket (42 teeth). A #40 industrial chain was used to connect the gear reducer to the power meter (Figure 2B). The sprocket mounted to the power meter was machined so that it could be mounted as if it were a standard cycling chain ring (130 mm bolt circle diameter, 114 mm inside diameter). Initially, we used standard bicycle gears and chain for this part of the transmission; however, the sustained high powers associated with eccentric cycling training (eg, 20 min, 600 W) caused failure of the gear teeth and chain quickly. After these modifications were made, the transmission system was joined to the ergometer with a custom fabricated frame that also allows adjustment of chain tension by means of a turnbuckle (Figure 2B). Finally, the ergometer and transmission system were secured to the floor to minimize movement.

**Power Measurement Device**

A Schoberer Rad Messtechnik (SRM, Jülich, Germany) power meter (Figure 2C) is used to quantify power, work, and pedaling rate and provide feedback which allows the individual to voluntarily resist the pedals at a prescribed target power. Because the SRM power meter is known to provide accurate measurements of cycling power, calibration of the eccentric cycle ergometer is achieved simply through calibration of the SRM system. Data recorded with the SRM power meter can be downloaded to a computer and analyzed. The SRM power meter was the single most expensive part of our eccentric cycle ergometer with basic models currently selling for about $2700 US currency. While this does represent a significant cost, our SRM power meter can be used on other laboratory ergometers as well as freely moving bicycles and thus is useful in a broad range of applications. Other options for power meters are available from manufacturers such as Quarq.

**Results**

The essential elements of our isokinetic eccentric cycle ergometer included (1) recumbent cycle ergometer frame and seat, (2) motor and speed controller to drive the cranks, (3) transmission system that allows for proper pedaling rates, and (4) power measurement device that provides feedback to the individual performing the exercise. Further, several modifications were made to ensure that the ergometer could withstand the repeated high powers associated with chronic eccentric cycling. Representative eccentric cycling power-time profiles recorded during continuous (20 min, target power of 600 W, 60 rpm) and incremental (30 s, target powers of 250, 500, 750, and 1,000 W, 80 rpm) exercise are illustrated for descriptive purposes (Figure 3).

**Discussion**

This technical note outlines the steps we used to construct an isokinetic eccentric cycle ergometer. The ergometer was built primarily from commonly available exercise equipment, industrial parts, and a modest amount of custom fabrication. With this ergometer, we have performed eccentric cycling trials across a broad range of powers and have used this device in both research and training. Based on our experiences, we point out several additional design and safety issues that should be considered when implementing eccentric cycling as an exercise modality.

The eccentric cycle ergometer crank axle is a standard cycling bottom bracket (Shimano UN54 68 × 113mm) and is not ideal for the high powers associated with eccentric cycling. While an alternative bottom bracket could be machined we believe that the economical solution is to use these standard bicycle parts and inspect and replace them often. Similarly, we use standard bicycle aluminum cranks. While we have not yet experienced a failure, we inspect our crank arms regularly and in the long term we plan to have stainless steel versions fabricated. Another issue to consider is that the threading on the bottom bracket and the pedals is oriented to prevent loosening during concentric cycling. This design, however, does allow loosening during eccentric cycling. Our simple solution to this issue is to use industrial thread locking compound (Loctite 242 blue threadlocker, Henkel Corp., Westlake, OH USA) on the bottom bracket cups and the pedals. In our original design we intended to avoid this issue by reversing the mounting of the entire system so that the thread orientation would prevent loosening. Unfortunately, we learned that the SRM power meter did not function in this configuration and thus we had to...
change that design by installing the SRM power meter in its normal configuration.

We must emphasize that eccentric cycling can be potentially injurious in at least two ways. First, performing eccentric cycling with a seat position that allows the knee to reach full extension could result in serious injuries to the knee joint, including anterior cruciate ligament tears, as the pedal could forcefully compress and/or hyperextend the knee. Thus, extreme care should be taken when selecting a seat position to prevent the knee from reaching full extension. Alternatively, a padded restraint could be added that limits knee extension but we have not yet fabricated such a restraint. Second, because eccentric cycling is a repetitive, high-force, multijoint exercise, it is easy to induce muscle damage and soreness in the lower limb.17,27,28,33 Indeed, most participants in our previous eccentric muscle damage study28 believed that we had selected an eccentric cycling protocol that was too short (~8 min) to induce muscle soreness. Twenty-four and 48 hr later, however, participants were very sore with muscle soreness ratings of up to 9.85 cm (0–10 cm visual analog scale). Similarly, Flann and colleagues17 demonstrated that eccentric naïve individuals who performed 20 min trials of eccentric cycling had five times higher levels of plasma creatine kinase and considerably more muscle soreness compared with eccentric trained individuals that performed the same protocol. In an absolute worst-case scenario, eccentric cycling could induce large-scale muscle damage, resulting in rhabdomyolysis and possibly even renal failure and death.34 Thus, eccentric cycling training programs should be administered with utmost caution, particularly with eccentric-naïve individuals. For examples of progressive eccentric cycling training protocols that minimize muscle soreness, we refer the reader

![Figure 3 — Representative eccentric cycling power-time profiles recorded during (A) continuous exercise at a target power of 600 W (60 rpm) and (B) incremental protocol in which an experienced individual targeted 250, 500, 750, and 1000 W (80 rpm). Note that dashed lines represent eccentric target powers.](image-url)
to several previous reports. It is also important to note that eccentric cycling may pose other risks that we have not yet discovered. Finally, like any novel exercise protocol it is essential to provide participants with clear instructions and several familiarization trials.

In summary, we constructed an isokinetic eccentric cycle ergometer suitable for research and training using commonly available parts along with some custom fabrication. We believe that this technical note can serve as a useful first step for researchers and clinicians who would like to employ eccentric cycling as an exercise modality.

Acknowledgments

We sincerely thank Dale Hoskins, Ron Greenwood, and Troy Danvers at the University of Utah Metals and Machine Shop for their technical assistance with constructing the eccentric cycle ergometer. We are also grateful to Paul LaStayo for his recommendations over the years with using eccentric cycling.

References


