COMPARISON BETWEEN THE SRM AND POWERTAP POWER METERS TO THE IBIKE PRO POWER METER

THESIS

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ABSTRACT

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TO THE IBIKE PRO POWER METER

by

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The purpose of this study was to compare the Schoberer Rad Messtechnik (SRM) and PowerTap bicycle-mounted power meters to the new iBike pro bicycle-mounted power meter, in order to determine whether the iBike pro, which measures power using wind speed, hill gradient, and the weight of the cyclist and their bike, measures power output as accurately as the SRM and PowerTap power meters, both of which measure power based on torque. Seven competitive cyclists and one competitive triathlete preformed three experimental trials. The three trials consisted of three different

experimental conditions: a radical hill climb and descent, a rolling training ride, and a flat time trial (during which sprint data were collected). The trials were preformed on the same day with a recovery period between. The SRM and PowerTap were extremely highly correlated during the hill climb, time trial, and sprint interval with correlations of 0.99 for each of the trials. The iBike was extremely highly correlated with both the SRM and PowerTap during the hill climb trials with correlations of 0.99 and 0.98 respectively. There was a significant mean difference between the SRM and both PowerTap and iBike during all of the trials; $F(2,14)=38.26$, $p=.000002$ (hill climb), $F(2,14)=17.00$, $p=.00018$ (training ride), $F(2,14)=32.49$, $p=.000005$ (time trial), $F(2,14)=22.32$, $p=.00004$ (sprint interval), and $F(2,14)=14.47$, $p=.0001$ (all trials). There was not a significant mean difference between the PowerTap and iBike during the hill climb $t(7)=0.58$, $p=.29$, training ride $t(7)=0.61$, $p=.28$, and sprint intervals $t(7)=1.65$, $p=.07$, but was a significant mean difference during the time trial and all trials combined. In conclusion, the iBike may be less consistent when compared to the SRM and PowerTap because of the large number of variables that are used by the iBike to calculate power. However, based on the high correlation between the iBike and both the SRM and PowerTap, it is likely that the iBike could be used for a power based training program. Nevertheless, coaches and exercise scientists should be cautioned about using the iBike or any power meter to determine very small changes in power output.

CHAPTER I

INTRODUCTION

For decades power output has been used to measure the intensity of cycling in a laboratory setting. However, with the recent development of bicycle-mounted power meters, such as the Schoberer Rad Messtechnik (SRM), PowerTap, Ergomo Sport, Polar, and iBike pro power meters, it is now possible to measure cycling intensity (power output) in the field (9). Cyclists can view real-time data relating to power output, and therefore are able to monitor their own intensity level during training, time-trialing, or racing (9). However, the accuracy of bicycle-mounted power meters is still up for debate. Research has shown that the SRM and PowerTap bicycle-mounted power meters may be accurate enough to be used by recreational cyclists (15), but whether or not newer and less expensive devices such as the iBike pro are accurate enough for a recreational cyclist remains to be seen. According to the manufacturer of the iBike pro, it has precision accuracy comparable to the highest-priced power meters (16).

Currently several prominent cycling coaches are using power-based training programs with both their recreational and elite-level cyclists. Joe Friel (14), who trains both cyclists and triathletes and Chris Carmicheal (18), who is best known for coaching Lance Armstrong to seven Tour de France wins, both recommend power-based training using bicycle-mounted power meters. However, with the accuracy of bicycle-mounted power meters in question, both recreational and elite-level cyclists should be cautious about relying to heavily on power-based training until additional data are obtained. This is especially true for elite-level cyclists, where a lack of accuracy in a bicycle-mounted power meter may not indicate small changes in power output (15, 26). These small changes at the elite level may be the difference between finishing 1st or 15th.

Nevertheless, if some, if not all of these bicycle-mounted power meters are shown to be accurate, then power based training may become the norm rather than the exception. Power output is a more direct measure of intensity than heart rate, and therefore may be a better tool for monitoring cycling intensity (9). Heart rate is affected by hydration, temperature, and ergogenics (e.g. caffience), and does not show instantaneous changes in intensity because of factors such as heart rate lag (9). Power meters may be the future of training in cycling, but it is important to ensure that the data people are using to create these power-based training programs are coming from accurate equipment.

Purpose

The purpose of this study was to compare the Schoberer Rad Messtechnik (SRM) (made in Germany by the SRM company) and PowerTap (made in Madison, Wisconsin by the Saris Cycling Group) bicycle-mounted power meters to the new iBike pro bicycle-mounted power meter (made in Ennis, Montana by Velocomp LLP), in order to determine whether the iBike pro, which measures power using wind speed, hill gradient, and the weight of the cyclist and their bike, measures power output as accurately as the SRM and PowerTap power meters, both of which measure power based on torque.

Hypotheses

1. It was hypothesized that the relationship between the power outputs recorded by the iBike pro power meter when compared to the SRM and PowerTap power meters over flat or slightly rolling terrain would be positively correlated.
2. It was hypothesized that the iBike pro power meter would record higher power outputs when compared to the SRM and PowerTap power meters during a radical hill climb and descent.
3. It was hypothesized that the iBike pro power meter would record lower power outputs when compared to the SRM and PowerTap power meters during short all out sprints.
4. It was hypothesized that the power outputs recorded by the SRM would be slightly lower than the power outputs recorded by the PowerTap power meter.

Delimitations

1. The study was delimited to men between 20 and 40 years old.
2. The study was delimited to men that are competitive cyclists or triathletes.
3. The study was delimited by measurements being taken by the SRM, PowerTap, and iBike pro bicycle-mounted power meters.

Operational Definitions

1. Bicycle-Mounted Power Meter - a device on a bicycle that allows for measurement of power output of the rider
2. Schoberer Rad Messtecnik (SRM) - a torque-measuring crankset used to measure power output
3. PowerTap - a torque-measuring hub that is built into a wheel to measure power output

4. iBike pro – a device on a bicycle that measures power using wind speed, hill gradient, and the weight of the cyclist and their bike
5. Stationary trainer – a device that allows a cyclist to warm-up or train in one place when they strap their bicycle into it

<u>Significance of Study</u>

With the recent development of an increasing number of bicycle-mounted power meters, and the development of training programs based on power, it is imperative that the accuracy of such devices be determined. Presently, it has been shown that some of the more expensive power meters, such as the SRM and PowerTap that measure power output based on torque at the crank or hub are accurate enough to be used by recreational cyclists in their training (15). The SRM ranges in price from $2,000 on the lower end to $4,000 for the most expensive models. Similarly, the PowerTap ranges from $1,000 on the lower end to $1,700 for the upper end models. Plus, the PowerTap requires instillation of the PowerTap hub into the rear wheel which increases the overall cost. Recently, newer and less expensive bicycle-mounted power meter like the iBike pro have been developed, but there accuracy has not been shown. The iBike pro is much cheaper than either the SRM or the PowerTap, with the base model without cadence running $450 and the cadence package costing around $100 more. In addition, the iBike pro measures power in a very different manner than either the SRM or PowerTap. The iBike pro uses wind speed, hill gradient, speed, and the weight of the cyclist and their bicycle to calculate a rider's power output (16). Whether or not the iBike pro has precision accuracy comparable to the more expensive power meters, as it claims possess, needs to be tested (16). Therefore, it is a necessary that additional testing is carried out to determine the accuracy of the iBike pro when compared to bicycle-mounted power meters with known accuracy such as the SRM and PowerTap power monitoring systems.

With further research questions can be answer as to how accurate the iBike pro power meter is at measuring power output. In addition, further research will help determine whether the iBike, which is much less expensive than the SRM and PowerTap, is as accurate at measuring power at a much cheaper cost. Is the most expensive power meter necessarily the most accurate one? Or is the iBike pro just as accurate as the more expensive ones? Answers to questions like this may help recreational and competitive cyclists make decision as to which power measuring device gives them the best value for their dollar.

CHAPTER II

LITERATURE REVIEW

Power is a measurement of the work performed per unit of time and is measured in watts (14). The "work" performed in cycling is basically the gear size related to resistance and "time" is the cadence or the number of times during one minute that a pedal stroke is completed (14). If gear size is increased and cadence remains the same, power rises; or if gear size remains the same and cadence is increased, power again rises (14). Therefore, power is the most direct way of measuring intensity, and may account for as much as 95% of the variability in metabolic cost while cycling (9). Exercise science laboratories have been measuring power outputs of cyclists for decades, and have used the data they obtained to improve performance and training techniques of competitive cyclists.

With the recent development of bicycle-mounted power monitoring system, such as the Schoberer Rad Messtechnik (SRM) (measures torque at the crank), PowerTap (measures torque at hub), and Polar (uses a chain vibration sensor) power meters, cyclist are now able to receive real-time data and keep tabs on their own intensity level (9). However, the accuracy and use of such devices in training is still up for debate. Recent research suggests that the SRM, PowerTap, and Polar power meters are at least accurate enough for recreational cycling use, but whether or not these devices have sufficient accuracy to be used by elite-level cyclist still remains to be seen (15, 18, 26).

Significance

Since the accuracy of bicycle-mounted power meters is presently unknown, as well as the effectiveness of training based on power, it is important to look at all of the factors associated with measuring power. Exercise scientists therefore need to examine the types of power outputs that exist, the different power measuring devices, the exercise tests that are based on power, and how power can be used to predict cycling performance. Only through the investigation of the exact relationship among all of these factors, can exercise scientists hope to better understand the correlation between cycling performance and power.

Types of Power

In the study of power as it relates to cycling there are several different definitions of power. Most of the definitions are constant, but there is a small amount of variation that exists from study to study. The most basic measure of power is simply the mean power output over a duration of time (4, 11, 12, 15, 26, 32, 35). The shortest duration measurements of power range from 3-6 sec, and are referred to by two of different terms. Peak 3s power output (Pmech max) is the greatest power attained for 3 sec (36). Conversely, in some studies, similar duration all-out sprint effort is referred to as peak power output (PPO) or maximal power output (Wmax) (7, 21). The problem is that PPO and Wmax are also used in other studies to represent the maximal sustainable power outputs for durations anywhere from 30 sec to 4 min (2, 4, 6, 29, 30). The key to understanding which type of PPO or Wmax is being represented is to look at the context of its use in the study.

In addition to PPO and Wmax, there are several types of power measurements based on physiological responses in the body. The types of power that relate to physiological responses are as follows: the power output at onset of blood lactate accumulation (Wobla) (4, 6, 29), power output at lactate threshold (Wlt) (6, 29), maximal aerobic power (Wmap) (4, 28, 29), and power output at ventilatory threshold (Wvt) (28). All of these types of power are measure at a certain point during testing, so that exercise scientists can better understand the body's response to different levels of exertion.

Power Measuring Devices

With the advancement of technology power measurements can now be taken in both a laboratory setting and in the field. There are several companies that make accurate and reliable cycling ergometers for recording power output in a laboratory setting. In addition, companies have begun to produce more and more accurate and reliable bike-mounted power meters, such that it is now possible to record power output during training rides, time trials, and road races (4, 11, 12, 15, 26, 32, 35).

Ergometers

Most exercise physiology labs now have one form or another of cycle ergometer. Cycle ergometers come in different versions from the mechanically braked Monark cycle ergometer; which is considered the "gold standard" among cycling ergometers (19, 22, 29), to the air-braked Kingcycle cycle ergometer; which allows cyclists to be tested on their own bicycle in the laboratory (3, 28, 32). Versions like the Monark and Kingcycle ergometers are highly reliable, and if properly calibrated, can be used reliably to test cyclist performance in the laboratory or test the reliability of other power testing equipment, such as power meters (3, 22, 32).

Power Meters

In resent years, three companies have come out with bicycle mounted power meters (9). Schoberer Rad Messtechnik (SRM), PowerTap, and Polar have all produced devices that measure power in the field while a person is riding (9). This allows cyclists to be able to record their power output during training and racing with relative ease, giving them real-time feedback on intensity of there training rides or races. However, the cost of such devices; which for the more expensive ones is ten to twenty times or more the price of a heart rate monitor (which also measures intensity), has made them a costly device for measuring intensity (14). Even so, it has been shown that power output more accurately gauges intensity compared to a heart rate monitor (9). Also, heart rate monitors do not show instantaneous changes in intensity and heart rate is affected by other factors such as hydration, temperature, and ergogenics (e.g. caffeine) (9). With all that is good to be said about power meters, exercise scientists still have to determine whether these devices are reliable, accurate, and valid for measuring power output, and whether or not they are reliable for all groups of cyclists from amateurs to professionals.

The SRM power meter has been shown to measure power output relatively accurately in several studies (3, 15, 22, 32). In addition, the difference between power output recorded by a SRM and Monark cycle erogometer was reported to be only 2.36% (22). Interestingly, a difference of 2.36% is very similar to the losses that are normally associated with the drive train system (22). This is interesting because the SRM power meter measures power at the crank, and therefore would likely not account for such losses (22). However, one study did find a significant difference of 10% between the power output recorded by the SRM power meter and Kingcycle cycle ergometer (4).

When comparing the SRM and PowerTap power meters, it was found that both the SRM and PowerTap were valuable instruments for monitoring power output (15). However, exercise scientists and coaches should understand the limitations of detecting changes in performance that are less than 2%, which are relatively common among elite athletes (15). Joe Friel and Chris Carmicheal, both of whom are well known cycling coaches, use the PowerTap power meter to access clients' power in field tests, and have designed power based training around the PowerTap power meter (14, 18). It has been shown that the Carmicheal Training System (CTS) 8-min field test was effective in evaluating initial levels of fitness, and therefore could be used as the bases for a power training program (18). This suggests that the PowerTap power meter can be used as an effective tool for monitoring exercise intensity during training (18).

The power outputs recorded by the Polar S710 power meter have been shown to be significantly higher than those recorded by a SRM power meter (26). In addition, these differences increased with increasing pedaling cadence and exercise intensity (26). Based on these findings it seems that the Polar S710 may be a useful device for recreational cyclist, but would not be advised for use by elite cyclists or exercise scientists (26).

Overall, bicycle mounted power meters may be helpful in the monitoring of cycling intensity when compared to heart rate monitors (9). However, coaches and exercise scientists need to be aware that these devices are not as accurate or reliable as most laboratory cycle ergometers (15). It has even been reported that temperature affected the accuracy of the SRM and PowerTap power meters (15). Consequently, if a coach or exercise scientist is planning to use power based training methods, they need to be prepared to deal with a certain amount of error in bicycle-mounted power meters.

Exercise Tests Involving Power

Many of the cycling exercise tests performed in exercise physiology laboratories relate to the power output maintained by a cyclist or the power output that cause a cyclist to fatigue. The Wingate anaerobic test (WAnT), based on its original protocol, requires a cyclist to pedal as hard as they can for 30 sec against a constant force (5, 10). This allows exercise scientists to measure peak power output (highest average power for 3-5 sec), mean power (during the 30 sec period), and rate of fatigue (degree that power drops-off during the test) (5). However, since the protocol was originally developed in the mid-to late 1970s many exercise scientists have made adjustments to the original procedure (5, 10). These changes may make it more difficult to compare data since the protocols are not the same, therefore exercise scientists need to go back to a uniformed testing protocol (5, 10).

The measurement of all-out sprint ability is usually measure by an Inertial-Load (IL) test method (8, 23). During an IL test the resistance is provided solely by the moment of inertia of the accelerating flywheel (23). This allows exercise scientists to get reliable data for the torque-velocity and power-velocity relationships (23). It was even shown that the IL test may be a good alternative to the WAnT test to measure PPO because the IL test causes less fatigue, and therefore can be preformed more times by the subject being studied (8).

In order to determine maximal aerobic power output exercise scientists use an incremental exercise test usually referred to as a Maximal Aerobic Power (MAP) test (2, 3, 28, 30). The MAP test starts at a given power output and power is increased $5.0 \pm 0.2\%$ of a subjects PPO (determined in a habituation test) every minute until volitional exhaustion (2). The highest average power recorded during a 60 sec period during the MAP test is the subject peak power output (PPO) (2). Similar to the MAP test is the graded exercise test (GXT), which is used to determine lactate threshold and other physiological variables (24, 33). In a GXT, subjects start at a given power output (based on initial fitness) and power is increased every 3 to 5 min until exhaustion (24, 33). It has been shown that both the 3 min and 5 min protocols allowed the researchers to obtain similar data (24); however, the 3 min GXT tended to average about 24 min to complete, whereas the 5 min GXT took about 40 min to complete (24). Based on these findings, a great deal of time and money could be saved using the 3 min GXT when compared to the 5 min GXT (24). Along with all of the previously mentioned tests, exercise scientists can also record power during simulated laboratory-based time trials (4, 24, 32, 34).

Predicting Performance Using Power

In cycling, it may be possible to predict an athlete's performance based on their power output during testing or by having the cyclist vary their power output during competition. Based on a cyclist's power outputs and morphological characteristics during testing, scientists may be able to predict cycling performance over various terrains (29). In addition, cyclists can increase performance by altering their power output on certain terrains and under different wind conditions (1, 19, 33, 34). The potential even exists to mathematically model cycling performance based on power and other factors, such that exercise scientists are able to closely predict cycling performance during time trials by various cyclists (22). Power also allows scientists to monitor seasonal changes in performance, so that they can better predict power output during certain portions of the season, and make changes to training programs from season to season (30).

Mathematical Model of Road Cycling Power

If an exercise scientist is given all the parameters that influence cycling performance it may be possible to actually predict cycling performance and power based on those parameters. A mathematical model has been constructed based on aerodynamic resistance, wheel rotation, rolling resistance, friction losses in the wheel bearings, changes in potential energy, changes in kinetic energy, and frictional loss in the drive chain (22). The correlation between the model (predicted mean power output) and the actual mean power produced in a time trial was $R^2 = .97$ (22). This means that there is an extremely high correlation between the ability of the model to predict power based on previously mention parameters, when compared to the actual power recorded during the time trials. This confirms that at least to some extent it is possible to accurately model cycling power.

Predicting Performance in Time Trials

In cycling, many cyclists are deemed to be specialists at one particular form of cycling. Using power, exercise scientists have attempted to predict which cyclists are better suited for the individual discipline of time-trialing; since time-trialing is an individual all-out effort that allows for no draft or tactical riding. In endurance trained cyclists it has been shown that peak power output (PPO) is not an effective predictor of performance in an outdoor 16.1 km time-trial, but that average power output during the time-trial was a good predictor of time-trial performance (2). The reasons PPO may have been such a poor predictor in that study was that simple PPO failed to take into affect variations between peoples aerodynamics and body size. In another study, Nevill et al. (28) showed that in combination with body mass, PPO could be used as a good predictor of a 40 km flat time-trial and a 10 km hilly time-trial performance in competitive cyclists. The use of a power-to-mass comparison was more effective in explaining the variation among cyclists that exists in time-trial performance (28).

In order to evaluate the performance of professional road cyclists in relation to morphological differences, Padilla et al. (29) allowed coaches and the cyclists' actual roles in competition to place cyclists into various categories. They found that the power outputs of cyclists classified as time-trial specialists could best be explained by higher powers at lactate threshold (Wlt) and at the onset of blood lactate accumulation (Wobla) than any other specialized group (29). However, similarly to the results reported by Nevill et al. (28) on competitive cyclists (28), PPO could be a good indicator of short time trial performance, just not of the longer time-trials in which cyclists define as time-trial specialists are capable of performing well (29).

Predicting Performance on Flat and Hilly Terrain

In cycling, a cyclist's ability to climb hills or fly over flat terrain may determine the races that they are capable of winning. Therefore, exercise scientists have used power to help them determine which cyclists are better adapted to which races. In both professional and competitive cyclists it has been shown that peak power output (PPO) is a good predictor of a cyclist performance on flat terrain (28, 29). It has even been reported that among five different groups of professional cyclists that included everything from flat terrain riders to uphill riders, PPO was highest at 461 ± 39W in flat terrain specialist (29). Based on these results it seems that PPO is a very strong indicator of a cyclist's ability to ride fast on the flats.

In professional and competitive cyclists, it has been shown that peak power output (PPO) when expressed relative to body mass was also a good predictor of hill-climbing ability (28, 29). But this is only true in terms of PPO to body mass ratios; since it was also shown that in professional cyclists, PPO was lowest among the uphill riders when compared to all of the different specialized groups (29). However, when the PPO was expressed relative to body mass, professional uphill riders had the highest PPO to kg ratio of 6.47 ± 0.33 W/kg (28). They were followed by time-trial specialist, all terrain riders, and flat terrain riders, with PPO-to-kg ratios of 6.41 ± 0.12 W/kg, 6.35 ± 0.18 W/kg, and 6.04 ± 0.29 W/kg, respectively (29). Based on these results peak power output is only a good indicator of hill climbing ability if it is expressed as a ratio to body mass. This seems plausible because most good climbers are thinner, more trim individuals that are capable of producing less absolute peak power, but more relative peak power when compared to their flat or all terrain counterparts.

Variable versus Constant Power

In competitive cycling, there are few, if any, events that require cyclist to ride on perfectly flat roads that have little or no wind. Cycling is a sport that requires, at least to some extent, variability in intensity. The power required to go the same speed uphill or into a headwind is greater than the power required to go that speed on flat ground with no wind. Therefore, it is important to study cyclists' power outputs in real, or at least simulated, scenarios, and determine whether variable or constant power is the best approach to cycling. In addition, it is essential that the physiological effects on the cyclist are the same for constant and variable power outputs situations.

It has been shown both hypothetically by Atkinson et al. (1) and through testing on cyclists by Swain (34) that slight variations in power output can be used by cyclists when conditions are hilly or windy to improve performance. Atkinson et al. (1) showed through the use of a mathematical model created by Martin et al. (22), that there was a predicted savings of 126 sec for a 10 km hilly time-trial and for a 40 km windy time-trial. When compared to the actual number obtain on cyclists tested by Swain (34), the time savings of model used by Atkinson et al. (1) were only slightly greater. Based on these results it seems likely that using slightly more power when going uphill and into wind, and slightly less energy when going downhill and with a tailwind, can be a beneficial strategy for reducing times in time trials. It also seems likely that if these techniques can be beneficial in time trial, they will likely be of some benefit in road racing competition.

Since it is probable that power pacing strategies are more beneficial than constant power strategies, exercise scientists then need to look at the physiological effects of constant versus variable power output. In competitive cyclists it has been shown that there were no differences in mean heart rate, mean blood lactate concentration, mean rating of perceived exertion (RPE), or mean VO2 between cyclists using constant or variable power output strategies (19). When varying power by ± 5% over a time trial done at 78% of VO2max cyclists experience no additional physiological stress (19). In addition, it was found that triathletes could reduce their running performance if they varied their cycling power output prior to a high-intensity run (33). However, it is possible that the reduced power output in the final five minutes of the cycling portion of the test may have served to increase recovery prior to the run (33). In either case, it seems evident that varying power output moderately, can reduce performance time while causing no significant changes in physiological response.

Predicting Seasonal Changes in Power

It is obvious that with training and progression thoughtout the cycling season, power will increase as an athlete increases their endurance and becomes stronger. However, the time that these increases occur, and the extent that they increase a cyclist's power are important in the development of a seasonal training program for a cyclist. Coaches need to know how power changes from the base phase, to the pre-competition phase, and on into the competition phase of a cyclist's season.

In competitive cyclists in New Zealand, it has been shown that the greatest increases in peak power output (PPO) and mean power output took place during the base and pre-competition phases of the season (30). In the twelve competitive male cyclists studied, PPO increased from 405 ± 33W in the base period, to 427 ± 33W in the pre-competition phase (30). Similarly, mean power output during a 4km time trial increased from 353 ± 31W in the base period, to 373 ± 33W in the pre-competition phase (30). The changes that occurred between the pre-competition period and competition period were much smaller with PPO and mean power output increasing 8W and 10W, respectively (30). Collectively these data suggest that power output increases more dramatically in the earlier portion of the season, and therefore coaches need to concentrate their training effort on increasing earlier-season power production since focusing on early-season efforts may payoff with better results later in the season.

Power Output and Cadence

If power output is increased on a cycling ergometer, there tends to be a reduction in pedaling cadence in competitive cyclists, runners, and less-trained persons (20). To the contrary, a study of professional cyclists under similar conditions (cycling on an ergometer) found that in professionals, the most economical cadence increased with increased power output (13). Another study reported that power output was most economical at 80 to 100 rpm, but reduced at 120 rpm by 9% in competitive cyclist (27); although a study of recreational cyclists found power output greatest at 50 rpm and lower at both 90 and 110 rpm (25). In competitive cyclists it has also been shown that in an all-out sprint, power output was limited by muscle coordination above 120 rpm (31).

Based on these results, there appears to be a relationship between pedaling cadence, power output, and experience level. The more experienced a cyclist is, the higher their cadence tends to be as load is increased. Recreational cyclists tend to prefer lower cadences at higher loads; whereas, competitive cyclists tend to prefer intermediate cadences, and professionals prefer higher cadences with increased load.

Power Output During Races

Through the use of portable power meters, such as the SRM, PowerTap, and Polar power meters, it is now possible to record power data during road race events. With this capability exercise scientists can now analysis real-life data and better understand the changes in power output that occur during actual races. Based on these data it has been shown that criteriums and flat road races require professional road cyclists (both men and women) to spend more time in the higher power output ranges (11, 12). This is likely because criteriums and flat road races require many short bursts of speed, as riders accelerate out of a corner in criteriums or attack each other on the flats. In addition, professional road cyclists (both men and women) were found to have more sustained submaximal power output in hilly road races (11, 12). Hilly courses serve to limit drafting and offer less of an opportunity for multiple attacks; which may be the reason cyclists spend more time in the submaximal, and less time in the maximal power output ranges.

When looking at a multiple stage race ridden by six professional male cyclists, power output during the five mass-start stages was 220 ± 22W (35). This was higher than the average power output found for flat and hilly terrains in another study of 165W and 169W (12), respectively. However, the mean power outputs found by Vogt et al. (35) were still lower than mean power output found during criteriums of 250W (12). In addition to looking at power output, Vogt et al. (35) compared power output to heart rate in order to determine which better described race intensity. It was found that heart rate underestimated the time spent in intensity zones below and above lactate threshold, and overestimated time spent at moderate intensities (35). This result indicates that power output is likely a better qualifier of intensity than heart rate (35).

Summary and Conclusions

In order to better understand varying cycling abilities among cyclists it is important for exercise scientists and cycling coaches to examine power output in both a laboratory setting and in the field. Exercise scientists need to have an appreciation for the various types of power that cyclists produce; from the high peak power outputs produced during an all-out sprint (7, 21, 36), to the constant power output produced at different physiological markers (4, 6, 28, 29). In addition, there has to be accurate and reliable means of measuring different power outputs. The accuracy and reliability of devices such as laboratory-based cycle ergometer (3, 19, 22, 28, 29, 32) and bicycle-mounted cycling power meters (3, 22, 32) in the field is important because proper training and coaching is highly dependent on accurate and reliable power data. However, it is important to note that some power meters may not be accurate enough to clarify differences of less than 2%, and therefore may not be good enough to be used by elite athletes (15, 26).

For exercise scientists to accurately measure power it is also important that they use the proper cycling exercise test or develop a proper testing protocol to measure just the power output they desire. Long standing protocols like the Wingate anaerobic test have been used for decades, but there seems to be too much variation among studies on the exact procedure (5, 10). This means that exercise scientists may not be able to compare the anaerobic data obtained in different studies, since protocols may be different from one study to the next (5, 10).

Through the use of power and other physical factors it is now possible to mathematically predict cycling performance (22). In addition, the different types of power output can be good predictors of time trial ability and flat or hilly terrain prowess (28, 29). Moreover, the use of variable power into and with the wind and up and down hills may actually save cyclists valuable time in time trials (1, 34), without causing increased physiological stress on the body (19). Power can even be used to track seasonal changes for base to pre-competition and on into competition (30). What is surprising is that most of the changes in power output occur early in the season between the base and pre-competition phases of the season (30). This means that if coaches want to properly train cyclists, it is very important to concentrate on early-season training. When looking at cadence and power, there seems to be a relationship between pedaling cadence, power output, and experience level. The less experienced cyclists tend to adopt slower pedaling cadences at greater loads; whereas more experienced cyclists tend to adopt higher pedaling cadenced at greater loads.

Last and perhaps most important is to look at power output during races. Since cycling is a dynamic sport with constant changes in wind conditions, road conditions, and race conditions (such as some one attacking the field), it is important for exercise scientists and coaches to recognize the significances of power data collected during races. Criteriums tend to have the highest mean power outputs during the race (12). This is likely caused by the short duration and multiple attacks that occur in a criterium race. In both criteriums and flat road races more time tends to be spent in the higher power output ranges, as opposed to hilly races where racers spend more time in the submaximal power output ranges (11, 12).

With the advent of bicycle-mounted power meters, it is now possible to relatively easily track power output in the field. Since power output is a more direct measure of intensity than heart rate, it may be a better tool for monitoring cycling intensity (9). Now recreational and elite cyclists can obtain relatively reliable data of their power output, and track their own progress during the racing season. In addition, with the use of power-based training programs, such as the ones developed by Joe Friel (14) and Chris Carmicheal (17), cyclists can now train using power as a guide. However, they should be cautioned that at the elite level, small changes in power output may not be apparent (15, 26).

Future Directions of Study

In the future, the study of power output will likely remain an important topic in exercise science. However, there are certain arenas within cycling and power that need to be examined further. There needs to be more data gathered on the power outputs of female cyclists, and the variations that exist in power output among women. There also needs to be more research comparing cyclists' power outputs to other athletic groups. The only study of note on this topic is one of weightlifters compared to cyclists, it reported greater maximal strength and muscle power in the lower limbs of weightlifter than cyclists, but greater maximal workload ability while cycling in the cyclist group when compared to the weightlifters (17).

More testing should be done to further access the reliability and accuracy of all currently available power meters on the market. Since these devices are currently being used for power based training. Specifically, devices such as the relatively new iBike pro should be compared to power meters that are known to be relatively accurate, in order to see if the iBike pro has accuracy comparable to the highest-priced power meters, as the manufacturer claims (16). The efficacy of power-based training programs; such as those used by Joe Friel (14) and Chris Carmicheal (18), should also be examined in depth, to see if or how well these programs work when compared to traditional methods. Lastly, additional studies should look at the seasonal changes in power output that occur during the different phases of the training season. This is important because these studies could help clarify when the greatest gains can be made in training.

CHAPTER III

METHODS

Subjects

For this study 8 men and women that were either competitive cyclists or triathletes were recruited for testing. They ranged in age from 20 to 40 years old, and passed a cycling survey and physical activity readiness questionnaire. Every subject in the study was advised of it components and procedures, and was required to sign an informed consent form prior to participating in the study.

Tests

For this study subjects were asked to perform three trials that included three different conditions. The three different conditions included: a radical hill climb and descent, a flat time trial, and a ride over slightly rolling terrain. The radical hill climb and descent were performed on a steep hill with an average grade of 7.7%, and took 1.5-3 min. to climb and a 0.5-1 min. to descend for most of the cyclists. The flat time trial was approx. 5 miles in length, and began with a 15-20 sec. sprint. The ride over slightly rolling terrain was similar to a normal training ride, and was 6.5 miles in length. Each of the tests was no more intense than a hard training session for an experienced cyclist or triathlete. During the three trials the subjects were asked to ride a bicycle equipped with three power meters: a SRM, a PowerTap, and an iBike pro. During the testing the three bicycle-mounted power meters ran simultaneously and record the power outputs of each of the subjects.

Procedure

When subjects arrived at the test site they were asked to sign an informed consent form. Prior to testing, the handlebars on the bicycle being used for testing were adjusted to the height specification of the subject being tested. Subjects were asked to come to the testing site well hydrated and ready to perform, and to limit food consumption two to three hours prior to testing. They were shown the bicycle with the three bicycle-mounted power meters on it, and given the chance to ask any questions or bring up any concerns they may have had.

Prior to warming up the bicycle seat was set to the correct height based on the subjects height, and the subjects pedals were attached. Prior to testing the subjects were allowed to warm up for 10 minutes. Then the different power meters were setup according to the manufacturer's specifications. The zero offset was set on the SRM power meter. The torque offset was set on the PowerTap. The iBike pro's tilt offset was set, as well as, the weight of the cyclist, bike, and gear was keyed into the iBike. Then the subjects were required to do the coast down of the iBike, as the last step required in the iBike's setup.

During each trial the subject were followed by a car with hazard lights on in order to increase safety for the subject. The trials were performed in a specific order in order to limit fatigue of the cyclists, and were preformed on the same day separated by a period of rest. Subjects were asked to select the pedaling cadence that they preferred. Subjects were asked to ride each of the trials similar to how they would in training. They were asked to ride at their own pace, but to base that pace on the situation. Therefore, intensities were higher during the flat time trial and radical hill climb and descent than for the ride over slightly rolling terrain. Power output of each of the subjects was recorded by each of the three bicycle-mounted power meters simultaneously.

<u>Design and Analysis</u>

The power output recorded by the SRM and PowerTap bicycle-mounted power meters were compared to the power outputs recorded by the iBike pro bicycle-mounted power meters. This was done in order to determine the accuracy of iBike pro power meter when compared to the SRM and PowerTap power meters. In addition, further comparisons were made between the SRM and PowerTap to determine whether they recorded similar power output during each of the trials. The data were analyzed using a pearson-product-moment correlation to determine the relationship between the power output recorded by the SRM and PowerTap power meters and the iBike pro power meter. Linear regression models were generated to determine the degree of common variation among the measures. A repeated measures ANOVA and post-hoc paired t-tests were used to compare the different means recorded by the SRM, PowerTap, and iBike pro during the different trials. All statistical tests were conducted with an overall alpha level of .05.

CHAPTER IV

RESULTS

A total of nine subjects volunteered, and eight completed all three trials. Seven subjects were competitive cyclists from the Texas State Cycling Team, one was a competitive cyclist that was not a member of the team, and one was a competitive triathlete. Eight subjects participated in the all three of the experimental trials, and one took part in a pilot study prior to the experimental trials. The data from this subject were not included in the analysis. Subjects ranged from 20-40 years old with a mean of 24 ± 6.2 years. Subjects ranged in height from 68-73.5 inches with a mean of 70.4 ± 2.3 inches, and ranged in weight from 135-189 lbs. with a mean of 166.3 ± 19.1 lbs.

Correlations

The highest correlations were between the SRM and PowerTap during all of the different trials. The SRM and PowerTap were extremely highly correlated during the hill climb, time trial, and sprint interval with correlations of 0.99 during all the trials. In addition, the overall correlation of the SRM and PowerTap for all of the trials was very high at 0.98. The lowest correlation between the SRM and PowerTap was during the training ride. However, even during the training ride trials the SRM and PowerTap were still highly correlated at 0.93.

The iBike was extremely highly correlated with both the SRM and PowerTap during the hill climb trials with correlations of 0.99 and 0.98 respectively. The iBike was also highly correlated to both the SRM and PowerTap during the other trial, but to a lesser degree than the SRM and PowerTap were correlated to each other. Correlations for the iBike to the SRM ranged from 0.90 to 0.99; where as, correlations for the iBike to the PowerTap ranged from 0.87 to 0.98. Table 1 shows the correlation values (R), the slopes, and the tests of significance F ratios and p-values among the different power meter during the various trials preformed. Figures 1-5 show graphic illustrations of correlation matrices for the hill climb, training ride, time trial, sprint interval, and all ride data respectively. Figures 6-20 are scatterplots of the different power meters compared to each other during the various trials with lines of best fit and lines of identity.

Comparisons

Table 2 reports the mean power outputs (watts) and standard deviations for the various trials. During the hill climb there was a significant mean difference $F(2,14)=38.26$, $p=.000002$ between the SRM (225.25 ± 56.07 watts), and both the PowerTap (263.13 ± 70.87 watts) and iBike 266.46 ± 63.08 watts. Figure 21 demonstrates these differences. The post-hoc analysis of the three different power meters during the hill climb indicated that there was no significant difference $t(7)=0.58$, $p=.29$ between the PowerTap and iBike (see Table 3).

During the training ride there was a significant mean difference $F(2,14)=17.00$, $p=.00018$ between the SRM (181.11 ± 40.78 watts), and both the PowerTap (220.75 ± 47.92 watts) and iBike (226.79 ± 57.13 watts). Figure 22 demonstrates these differences. The post-hoc analysis of the three different power meters during the training ride indicated that there was again no significant difference $t(7)=0.61$, $p=.28$ between the PowerTap and iBike (see Table 3).

During the time trial there was a significant mean difference $F(2,14)=32.49$, $p=.000005$ between the SRM (221.72 ± 45.59 watts), the PowerTap (264.63 ± 53.11 watts), and the iBike (288.40 ± 62.31 watts). Figure 23 demonstrates these differences. The post-hoc analysis of the mean data for the three different power meters during the time trial further indicated that there was a significant mean power output difference among all the power meters (see Table 3).

During the sprint intervals there was a significant mean difference $F(2,14)=22.32$, $p=.00004$ between the SRM (433.69 ± 94.15 watts), and both the PowerTap (517.50 ± 96.42 watts) and iBike (491.28 ± 109.18 watts). Figure 24 demonstrates these differences. The post-hoc analysis of the three different power meters during the sprint intervals indicated that there was again no significant difference $t(7)=1.65$, $p=.07$ between the PowerTap and iBike (see Table 3).

When looking at all of the trials combined (the hill climb, training ride, and time trial) there was a significant mean difference $F(2,14)=14.47$, $p=.0001$ between the SRM (209.36 ± 50.14 watts), the PowerTap (249.50 ± 59.31 watts), and the iBike (260.55 ± 63.75 watts). Figure 25 demonstrates these differences. Post-hoc tests among the three power meters further revealed significant differences among the mean power outputs of all the three power meters if the three trials were combined (see Table 3).

Table 1. Relationship Among Power Measures for SRM, PowerTap, and iBike

	Predicted	Predictor	R	F	P	Slope
Hill Climb	PowerTap	SRM	0.99	362.6	0.00001	1.254
Hill Climb	PowerTap	iBike	0.98	262.3	0.00003	1.098
Hill Climb	SRM	iBike	0.99	341.5	0.00001	0.881
Training Ride	PowerTap	SRM	0.93	37.7	0.00086	1.091
Training Ride	PowerTap	iBike	0.87	19.2	0.00469	0.732
Training Ride	SRM	iBike	0.92	34.5	0.00108	0.659
Time Trial	PowerTap	SRM	0.99	279.5	0.00001	1.153
Time Trial	PowerTap	iBike	0.91	27.2	0.00198	0.772
Time Trial	SRM	iBike	0.90	24.6	0.00255	0.656
20s Sprint	PowerTap	SRM	0.99	653.9	0.00001	1.020
20s Sprint	PowerTap	iBike	0.91	29.7	0.00159	0.806
20s Sprint	SRM	iBike	0.92	33.5	0.001160	0.794
Overall	PowerTap	SRM	0.98	451.0	0.00001	1.155
Overall	PowerTap	iBike	0.92	122.1	0.00001	0.856
Overall	SRM	iBike	0.93	146.7	0.00001	0.733

Table 2. Means and Standard Deviations of the SRM, PowerTap, and iBike

Power Meter	Test	N	Mean	StDev
SRM	Hill	8	225.3	56.1
	Train	8	181.1	40.8
	TT	8	221.7	45.6
	Sprint	8	433.7	94.2
	All	8	209.4	50.1
PowerTap	Hill	8	263.1	70.9
	Train	8	220.8	47.9
	TT	8	264.6	53.1
	Sprint	8	517.5	96.4
	All	8	249.5	59.3
iBike	Hill	8	266.5	63.1
	Train	8	226.8	57.1
	TT	8	288.4	62.3
	Sprint	8	491.3	109.2
	All	8	260.6	63.8

Table 3. Post-hoc t-Test Results Comparing Means of the SRM, PowerTap, and iBike

Post-hoc t-Test for Power Meter	Trial	P-value
SRM vs. PowerTap	Hill	0.00019*
	Train	0.00023*
	TT	3.78E-06*
	Sprint	1.98E-08*
	All	1.77E-12*
iBike vs. SRM	Hill	5.38E-06*
	Train	0.00065*
	TT	0.00018*
	Sprint	0.00342*
	All	3.18E-10*
iBike vs. PowerTap	Hill	0.29
	Train	0.28
	TT	0.02*
	Sprint	0.07
	All	0.02*

* significant mean difference

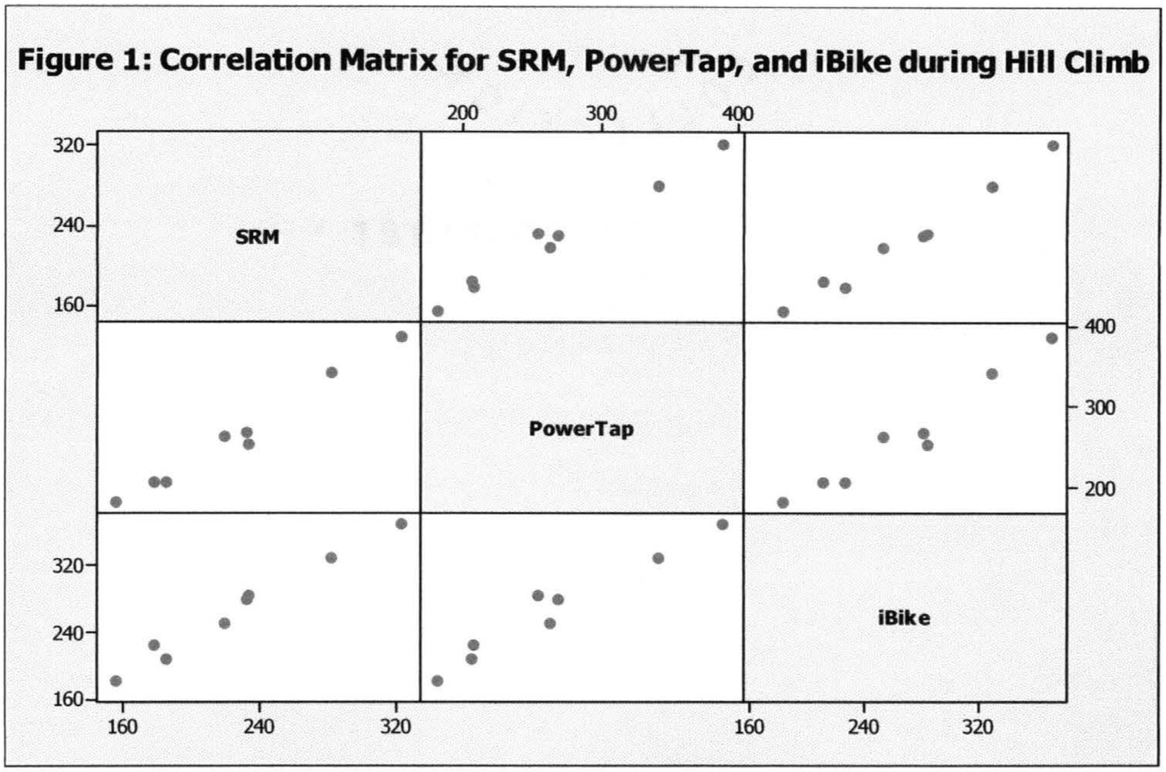

Figure 1. Graphic Illustration of Correlation Matrix during Hill Climb

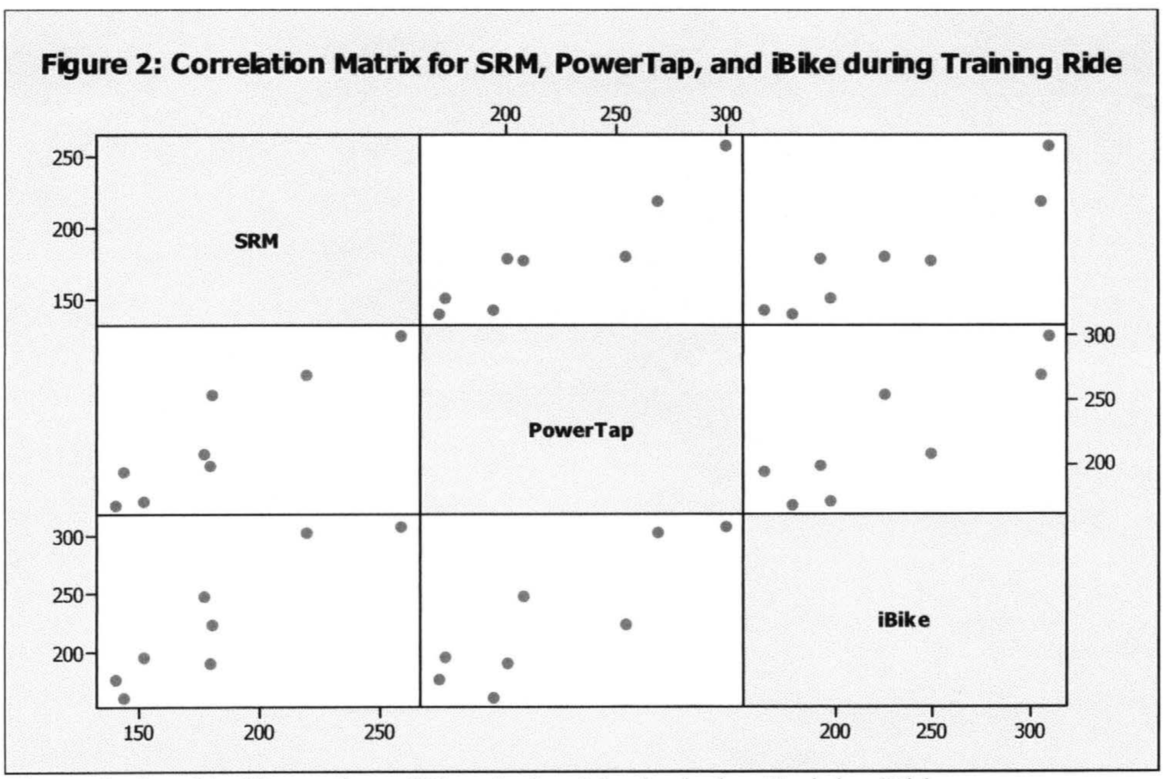

Figure 2. Graphic Illustration of Correlation Matrix during Training Ride

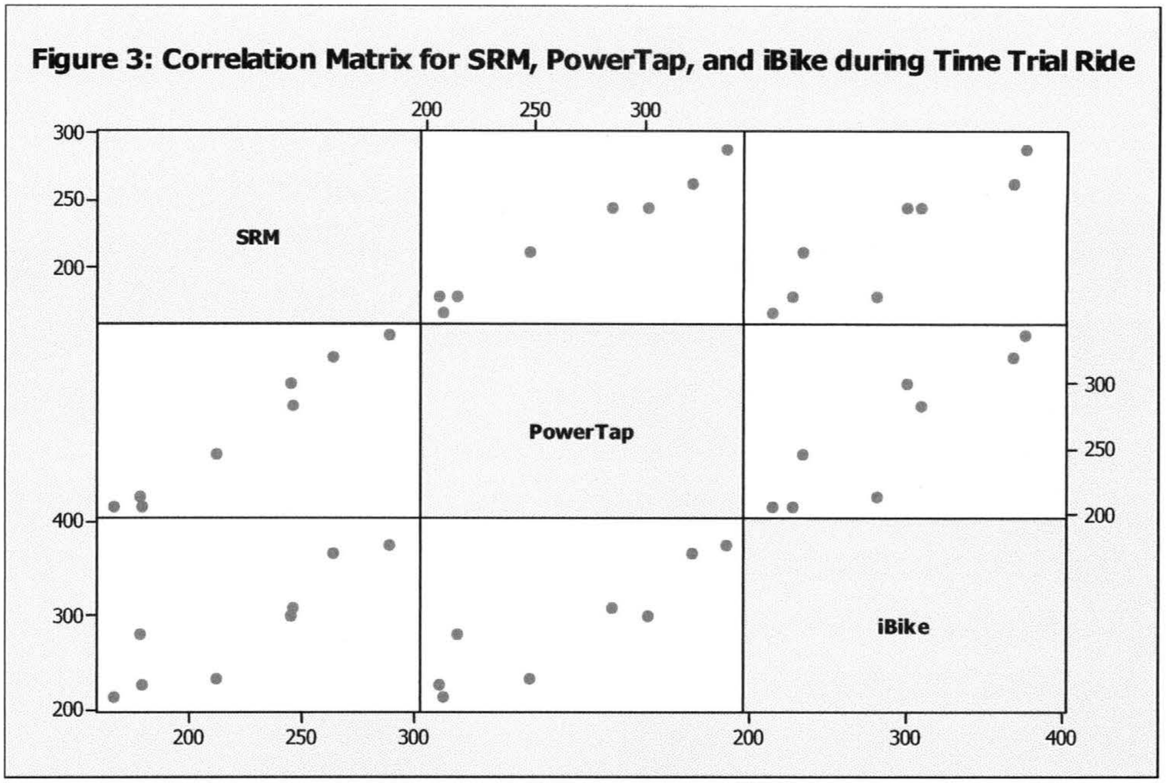

Figure 3. Graphic Illustration of Correlation Matrix during Time Trial Ride

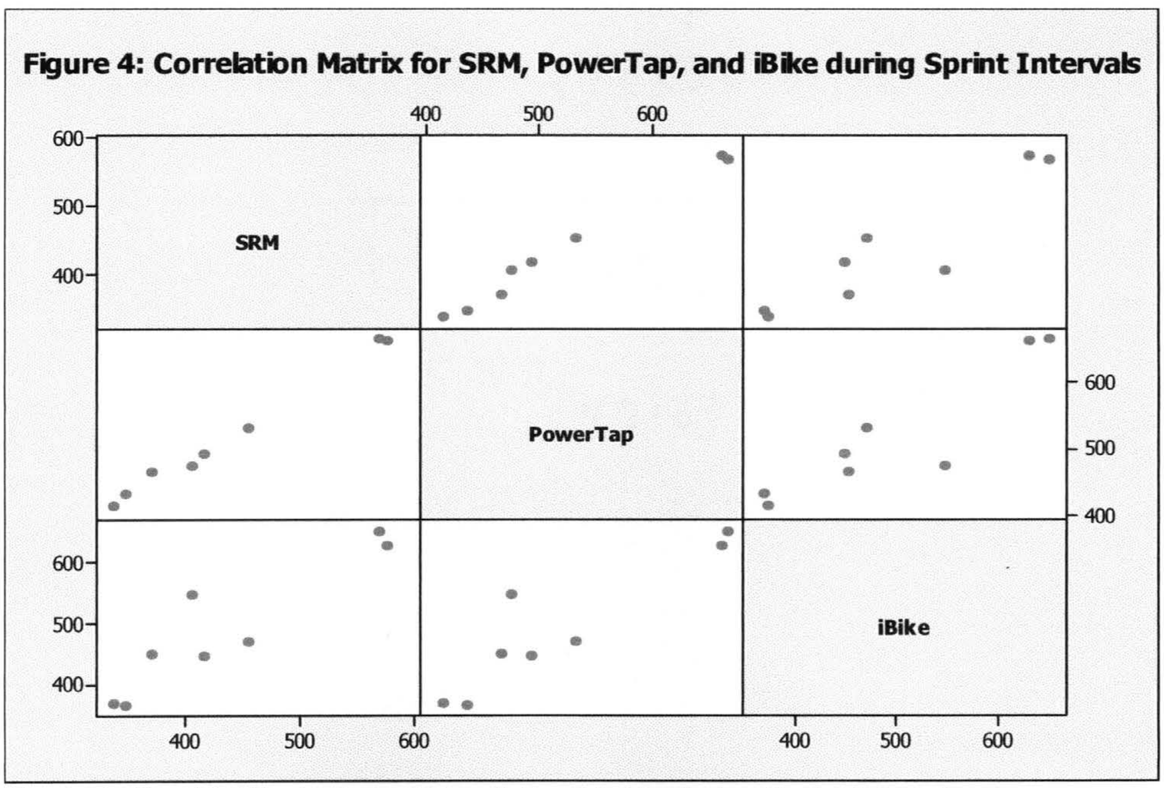

Figure 4. Graphic Illustration of Correlation Matrix during Sprint Intervals

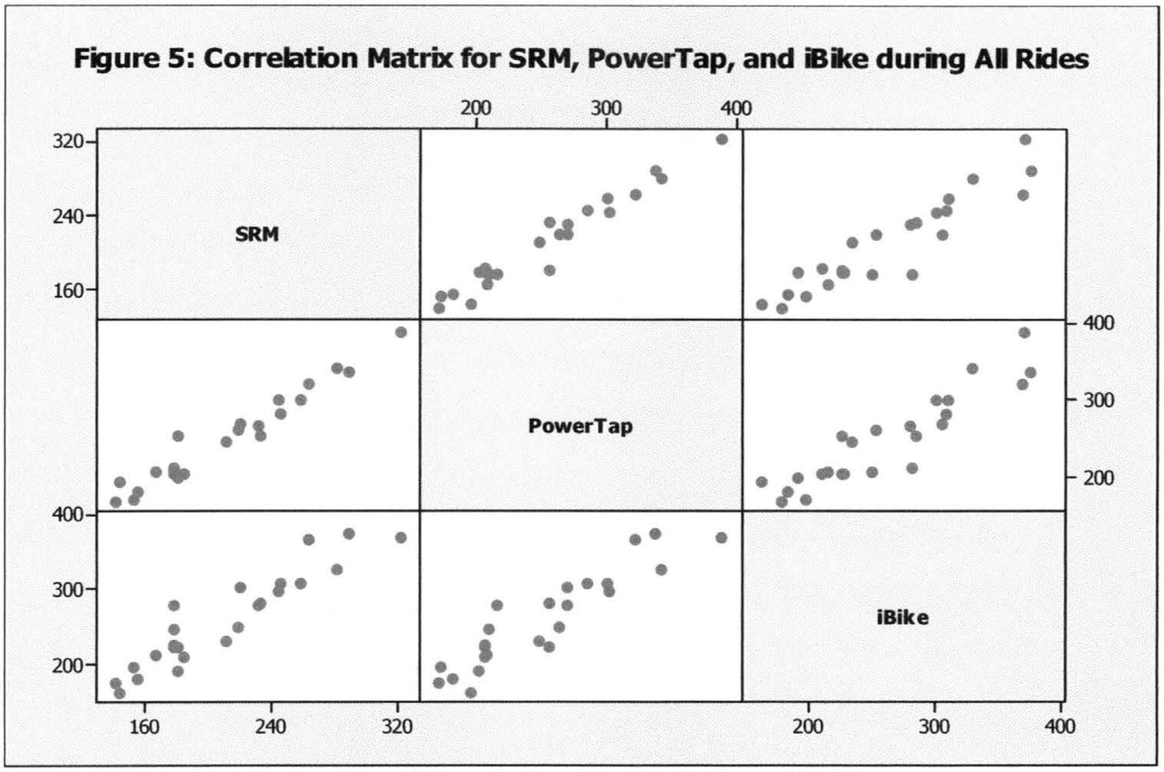

Figure 5. Graphic Illustration of Correlation Matrix during All Rides

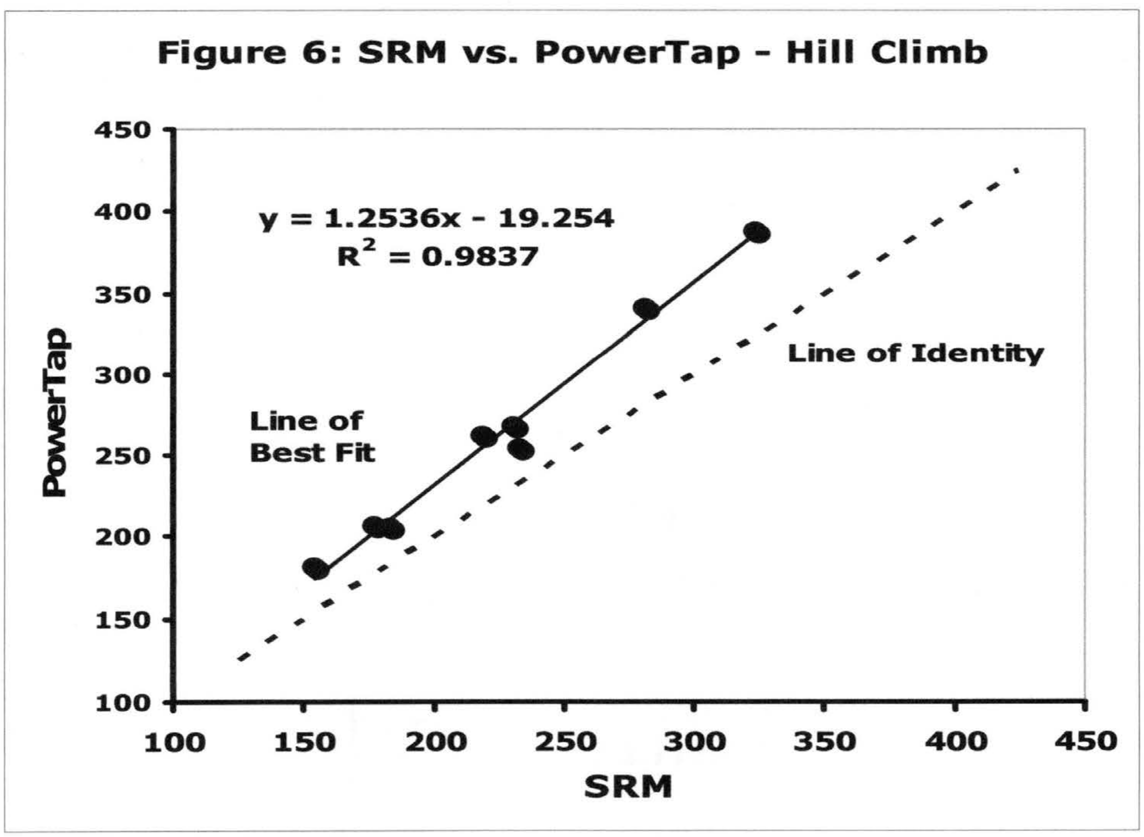

Figure 6. Scatterplot of SRM vs. PowerTap during Hill Climb

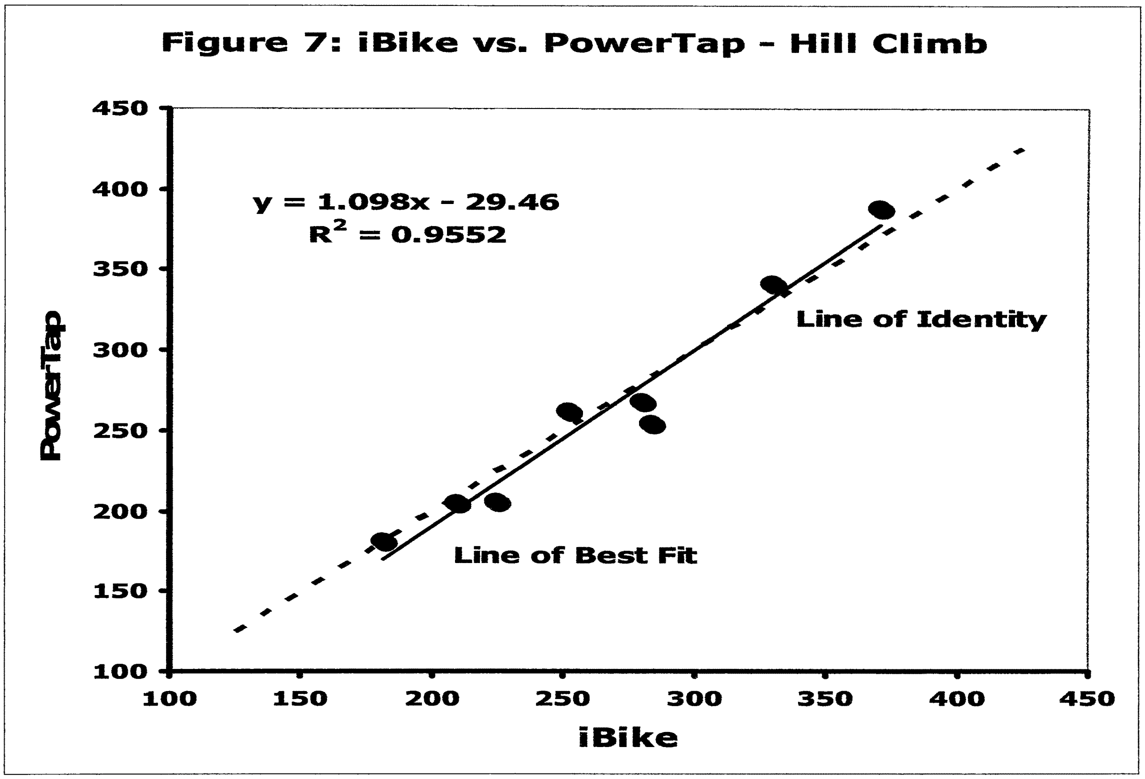

Figure 7. Scatterplot of iBike vs. PowerTap during Hill Climb

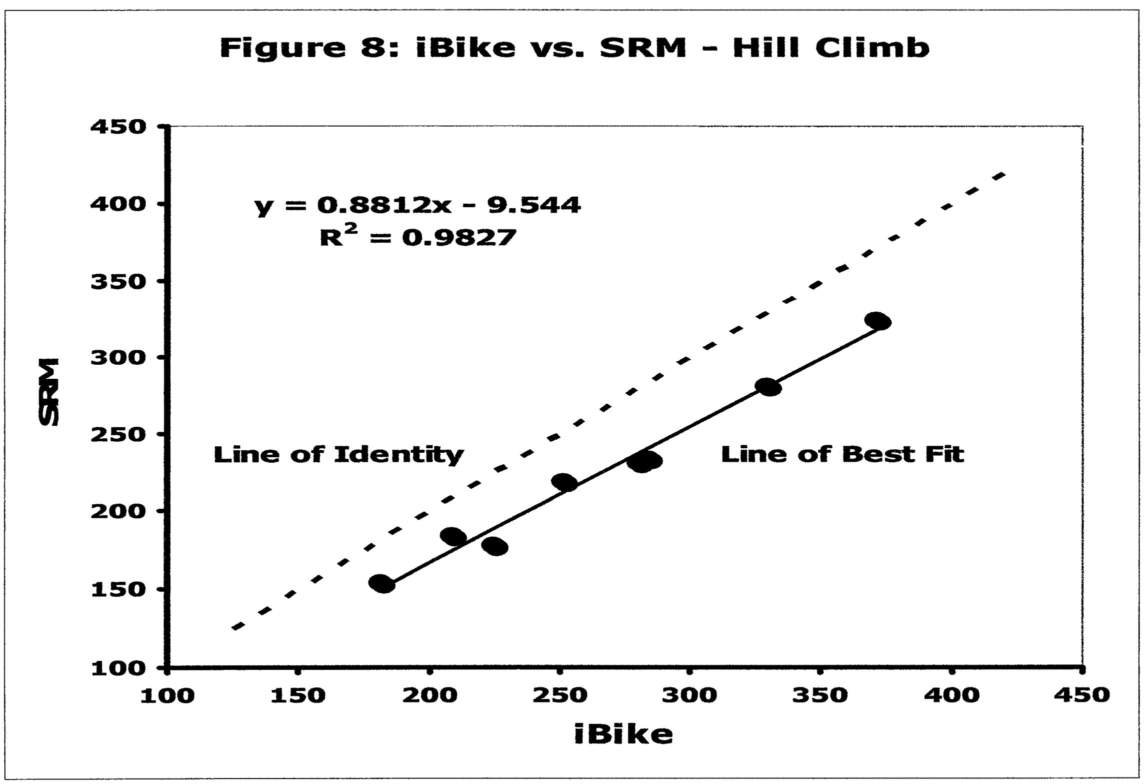

Figure 8. Scatterplot of iBike vs. SRM during Hill Climb

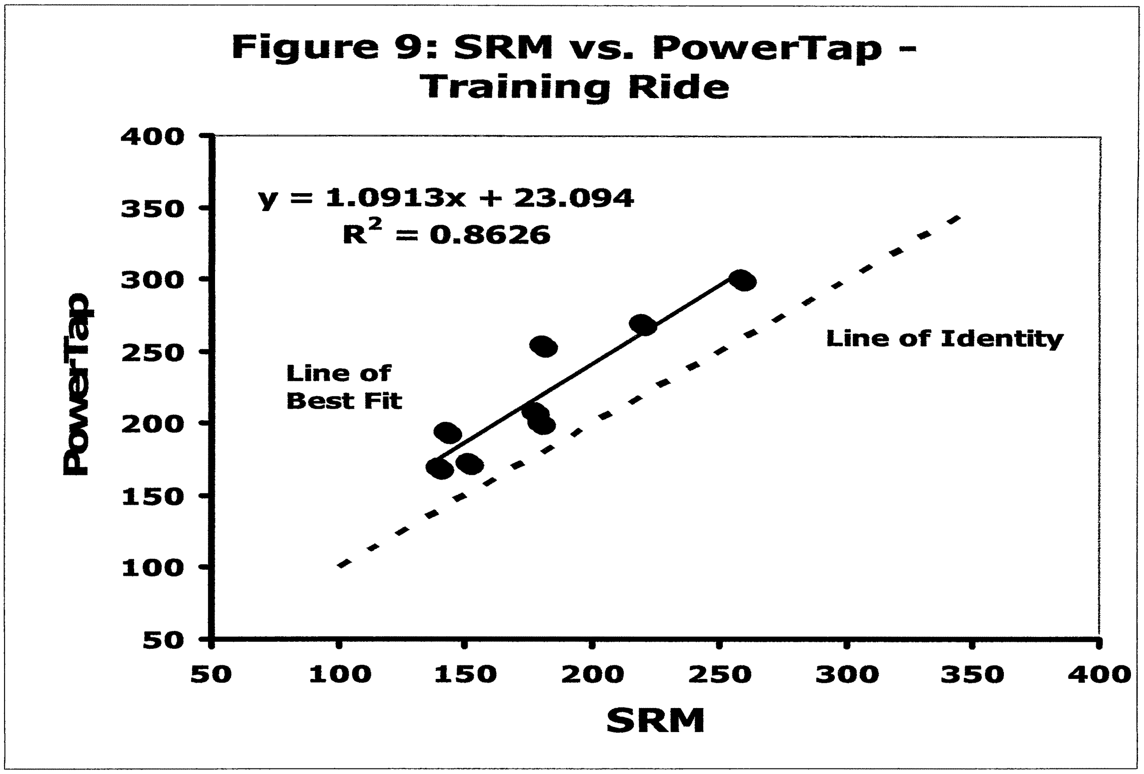

Figure 9. Scatterplot of SRM vs. PowerTap during Training Ride

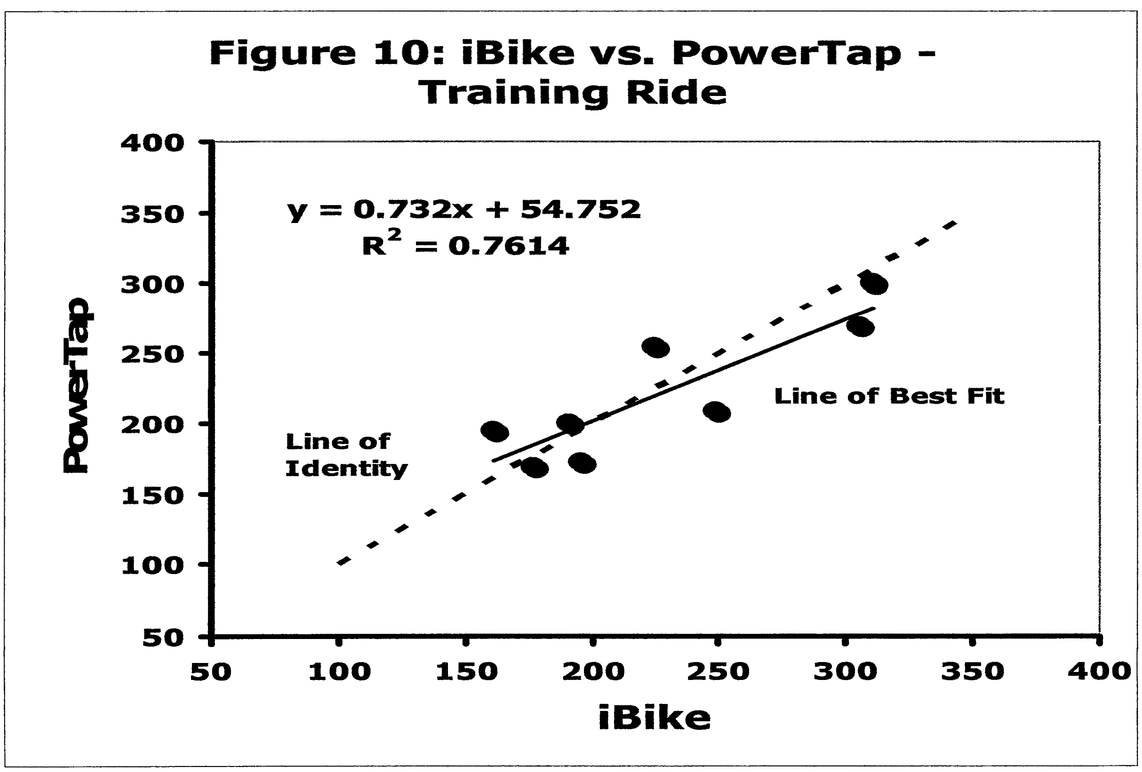

Figure 10. Scatterplot of iBike vs. PowerTap during Training Ride

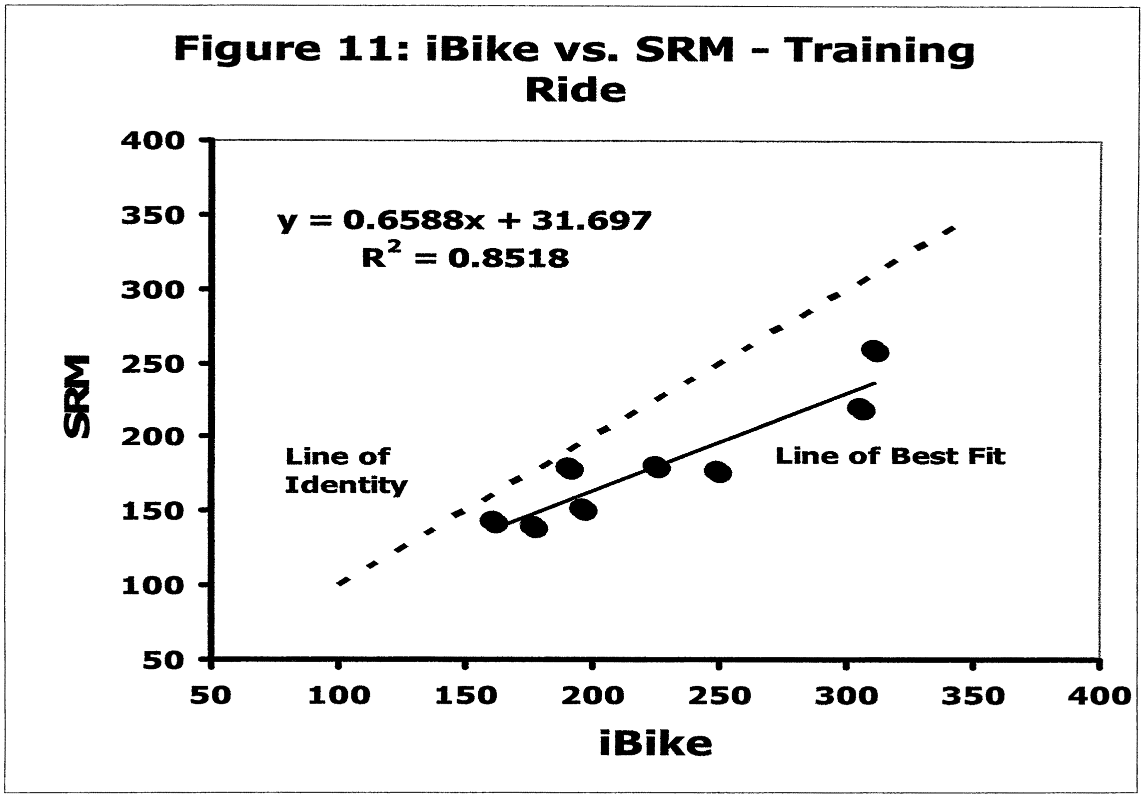

Figure 11. Scatterplot of iBike vs. SRM during Training Ride

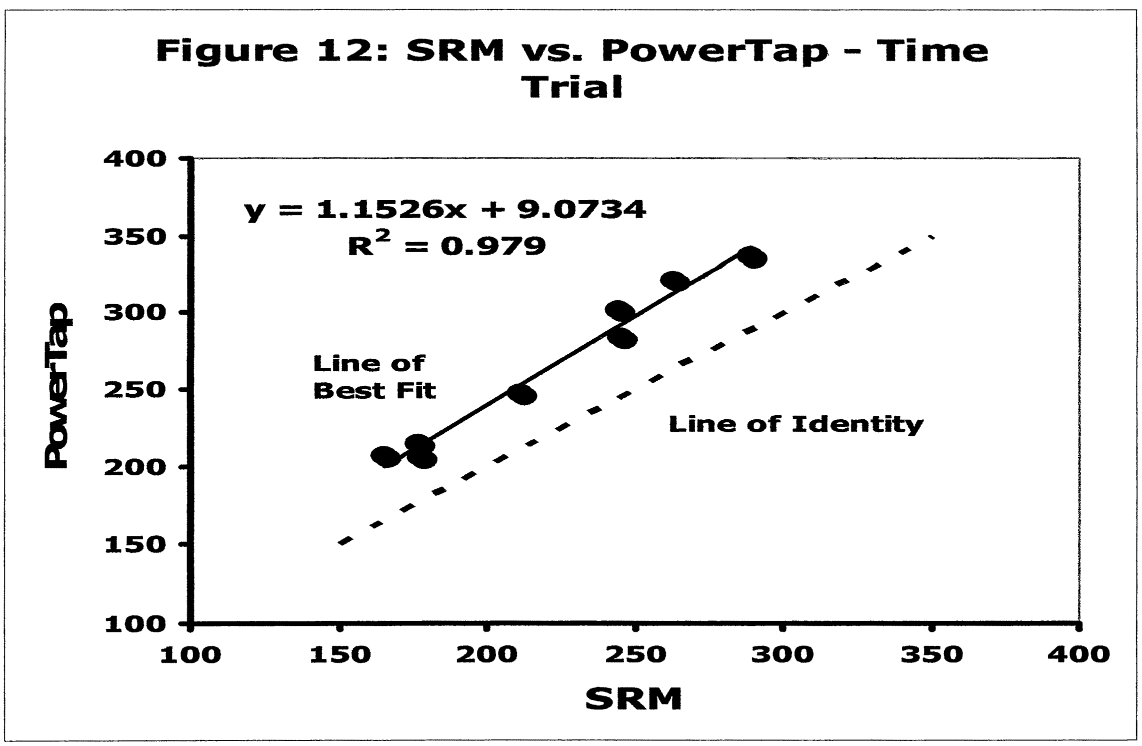

Figure 12. Scatterplot of SRM vs. Powertap during Time Trial

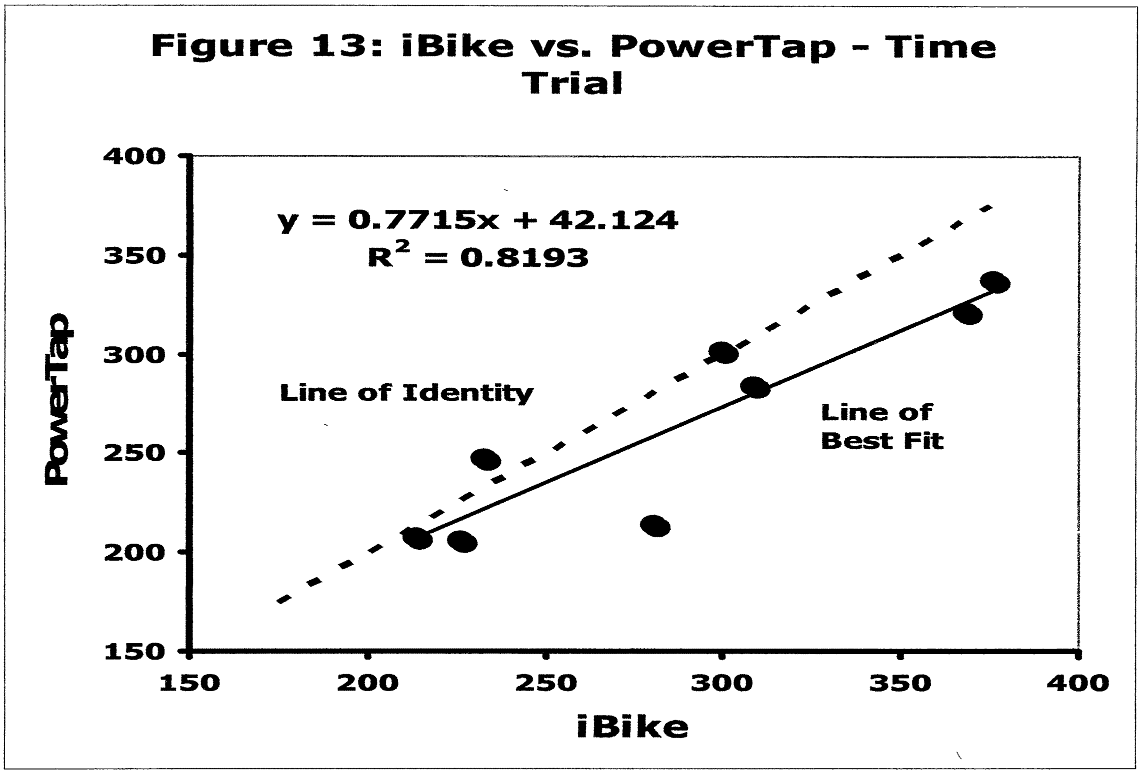

Figure 13. Scatterplot of iBike vs. PowerTap during Time Trial

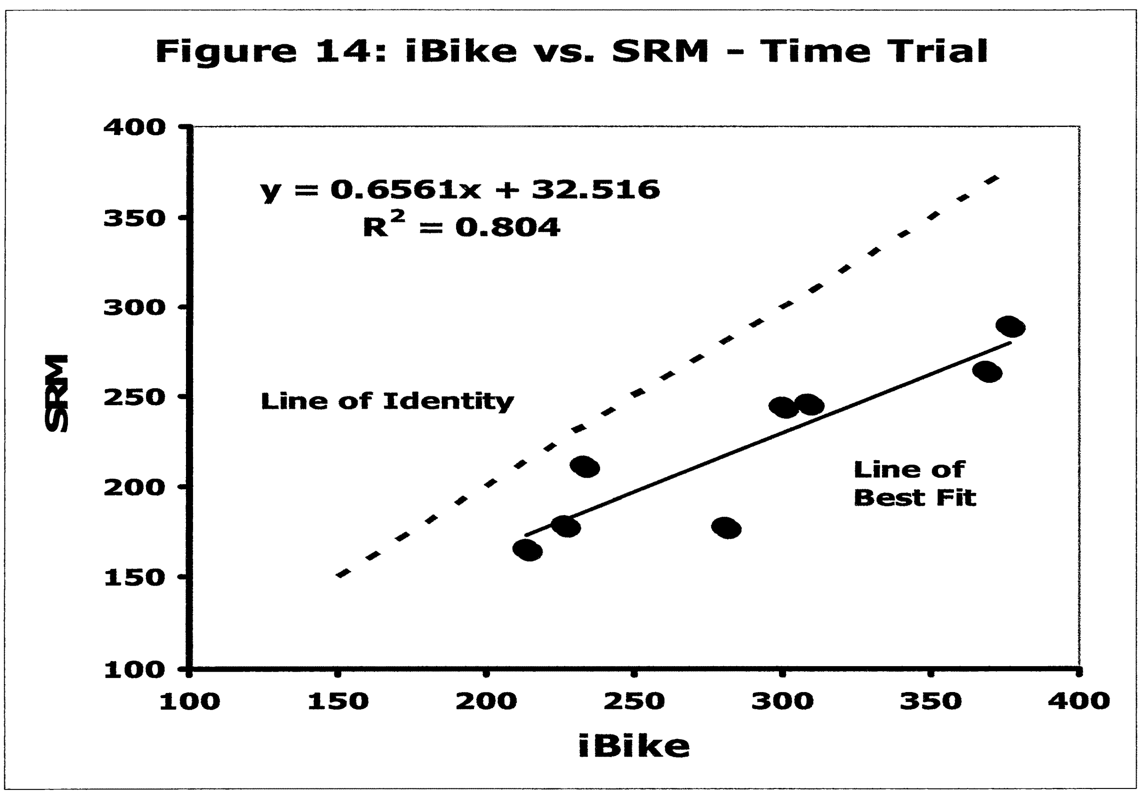

Figure 14. Scatterplot of iBike vs. SRM during Time Trail

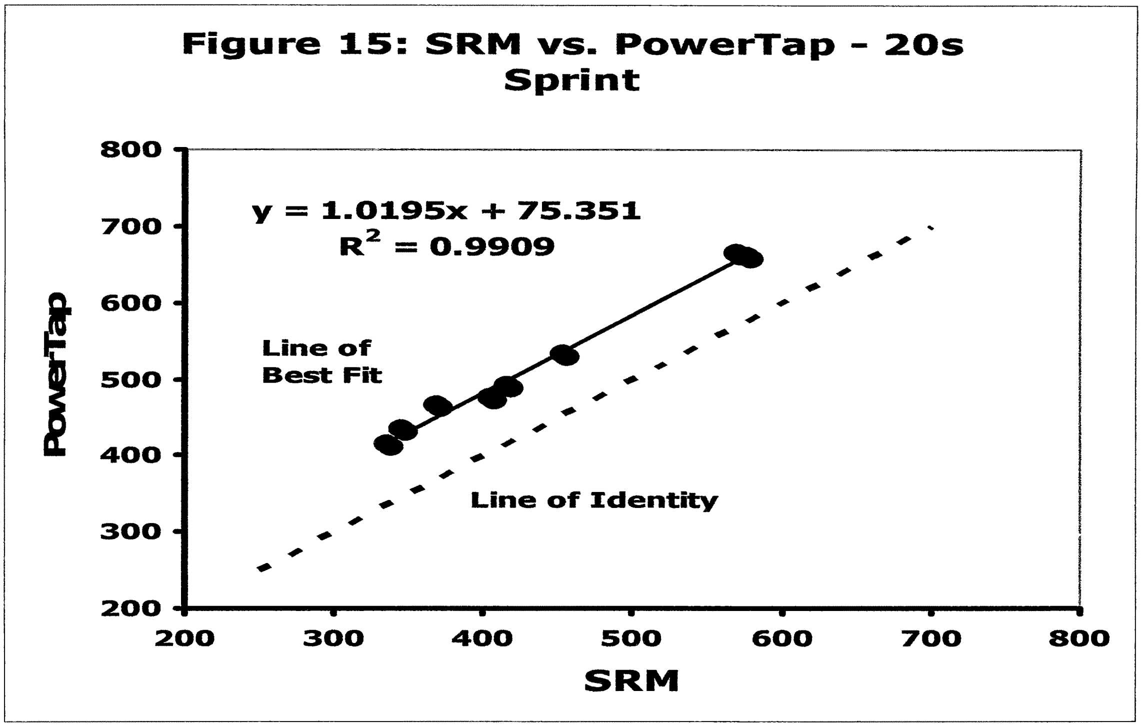

Figure 15. Scatterplot of SRM vs. PowerTap during 20 sec. Sprint

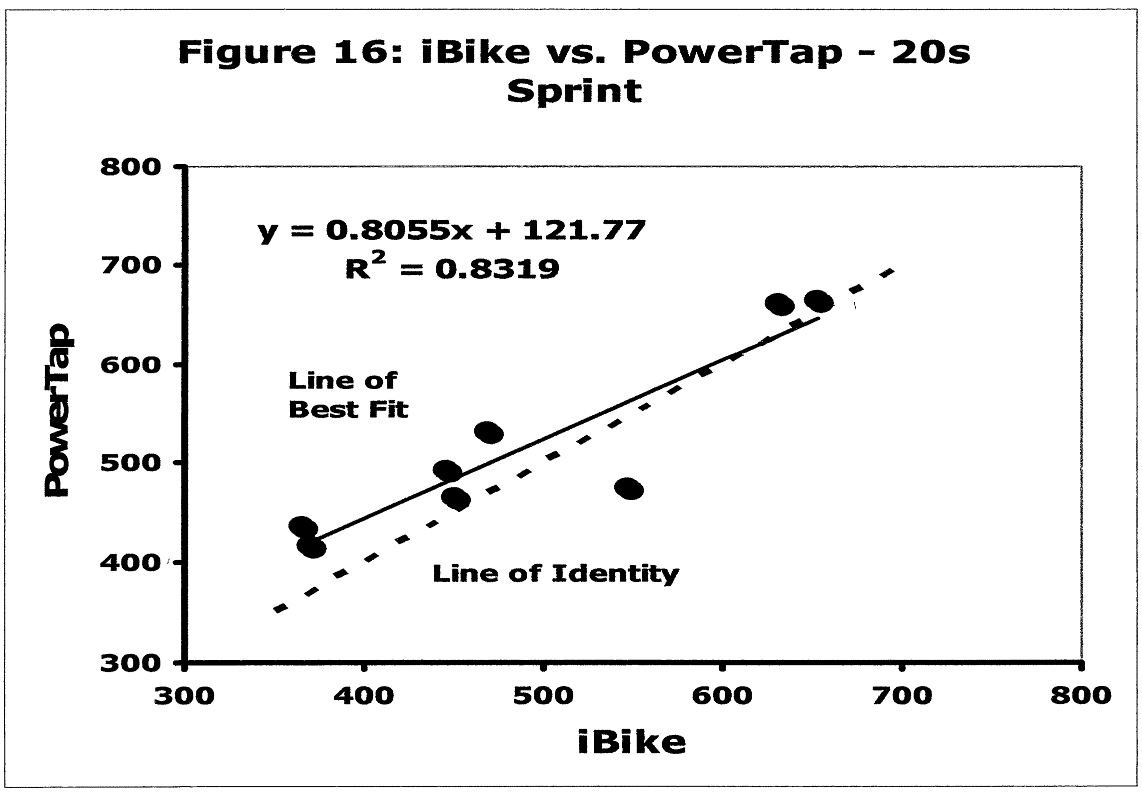

Figure 16. Scatterplot of iBike vs. PowerTap during 20 sec. Sprint

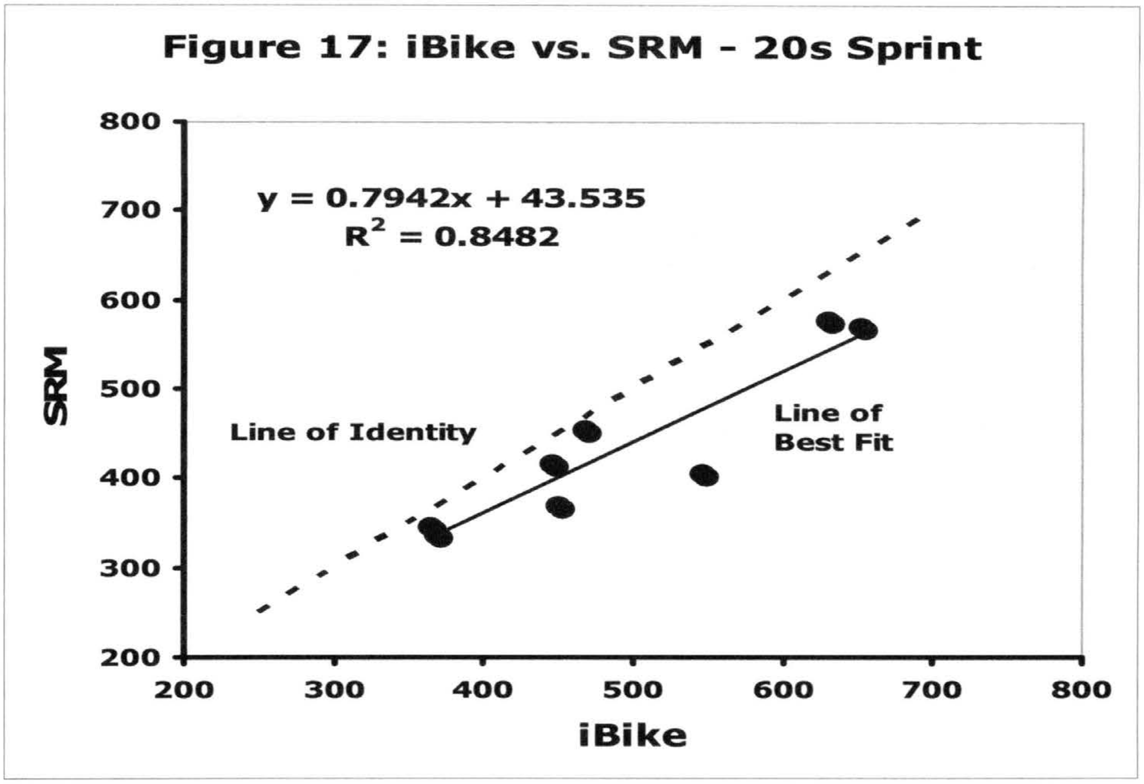

Figure 17. Scatterplot of iBike vs. SRM during 20 sec. Sprint

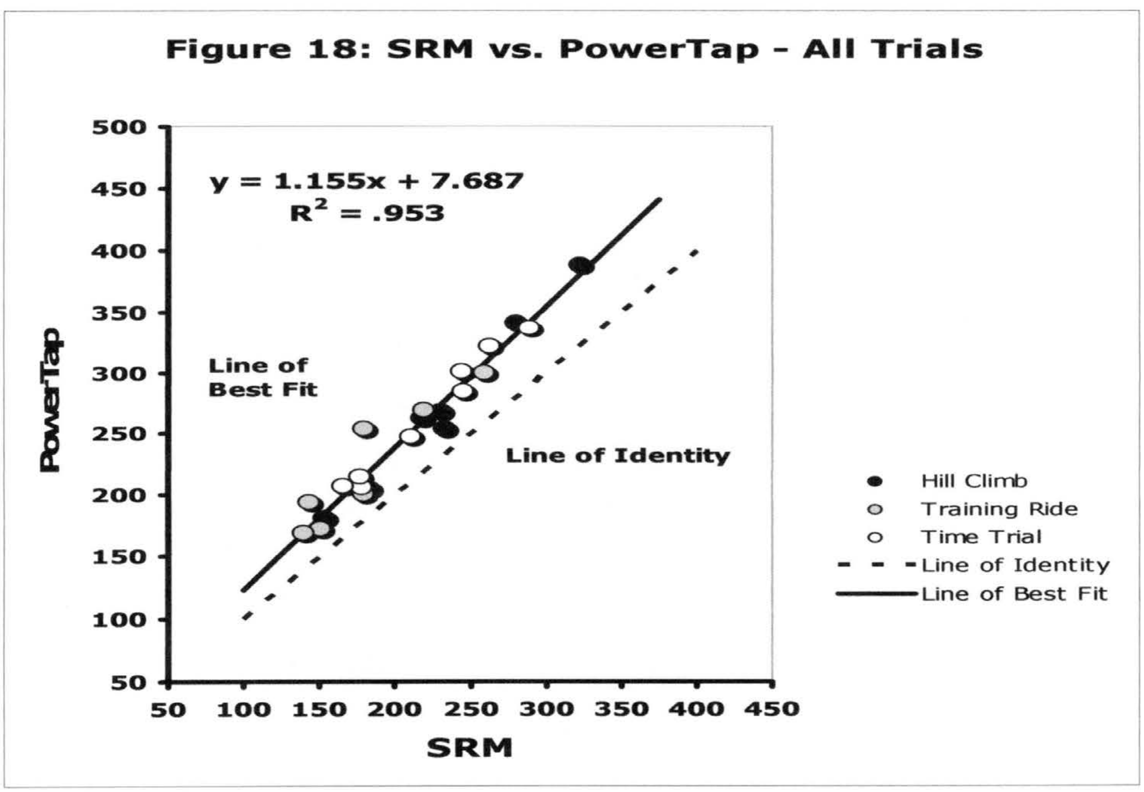

Figure 18. Scatterplot of SRM vs. PowerTap during All Trials

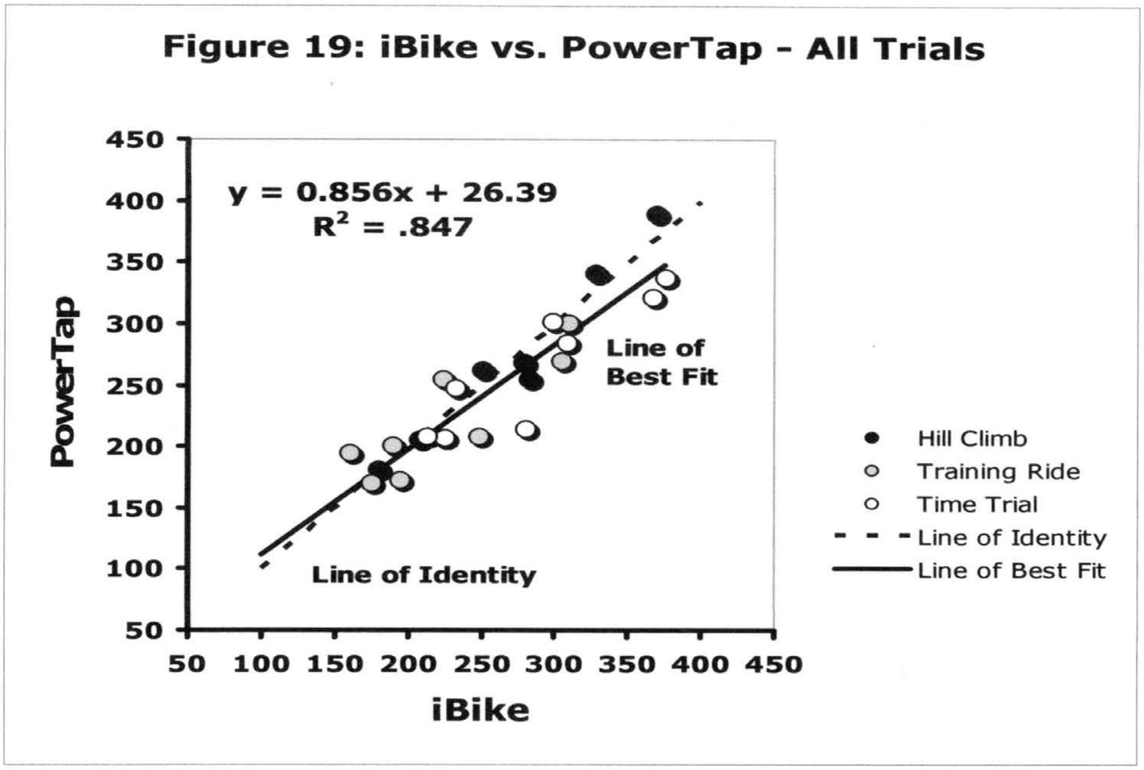

Figure 19. Scatterplot of iBike vs. PowerTap during All Trials

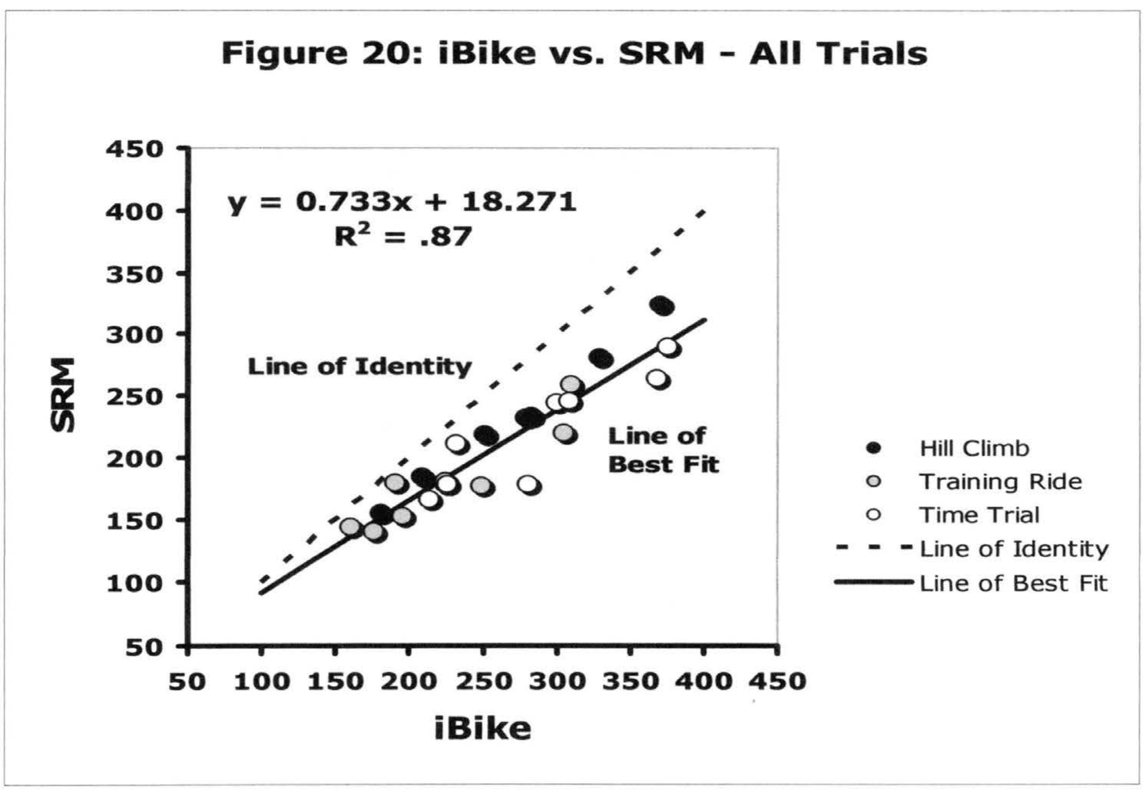

Figure 20. Scatterplot of iBike vs. SRM during All Trials

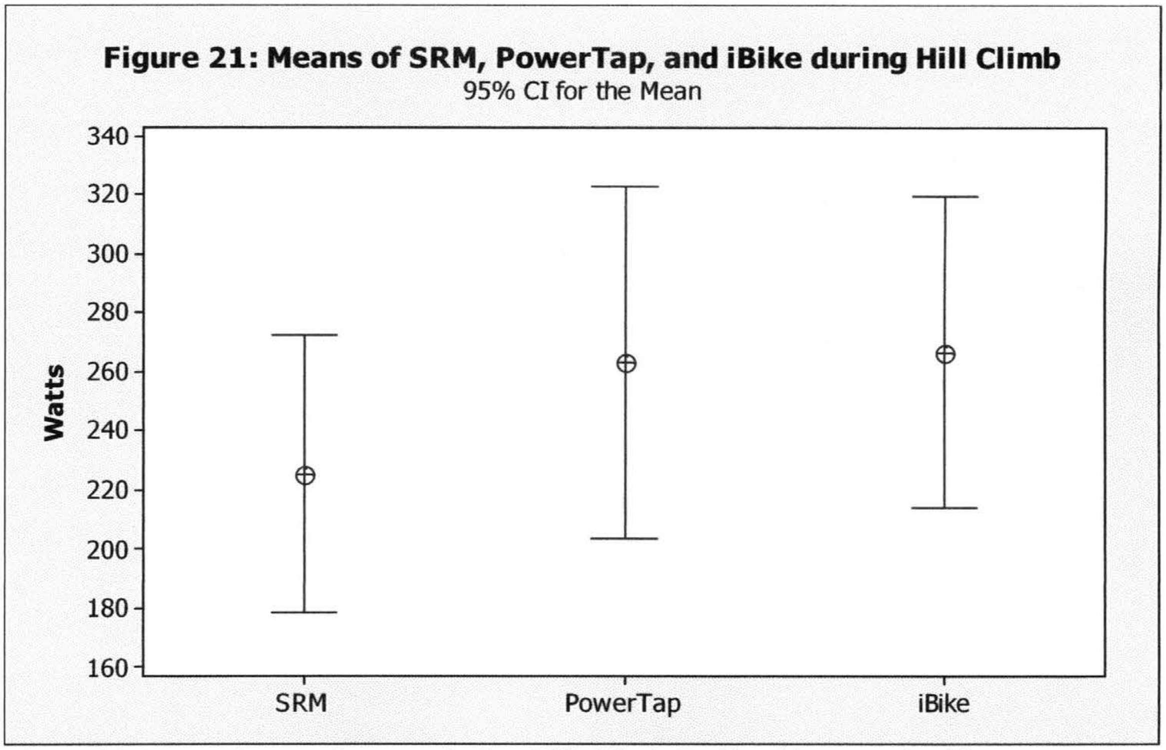

Figure 21. Means Power Outputs during Hill Climb Trails. Shows a significant difference between the SRM and both the PowerTap and iBike, but not a significant difference between the PowerTap and iBike.

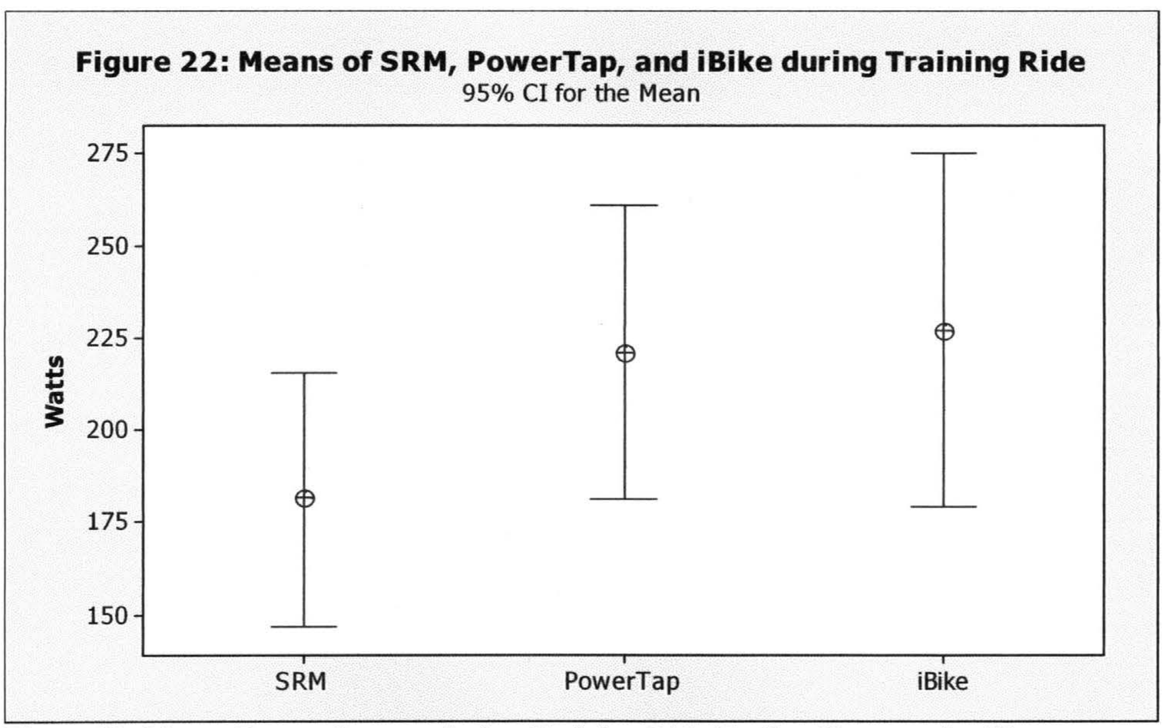

Figure 22. Means Power Outputs during Training Ride Trails. Shows a significant difference between the SRM and both the PowerTap and iBike, but not a significant difference between the PowerTap and iBike.

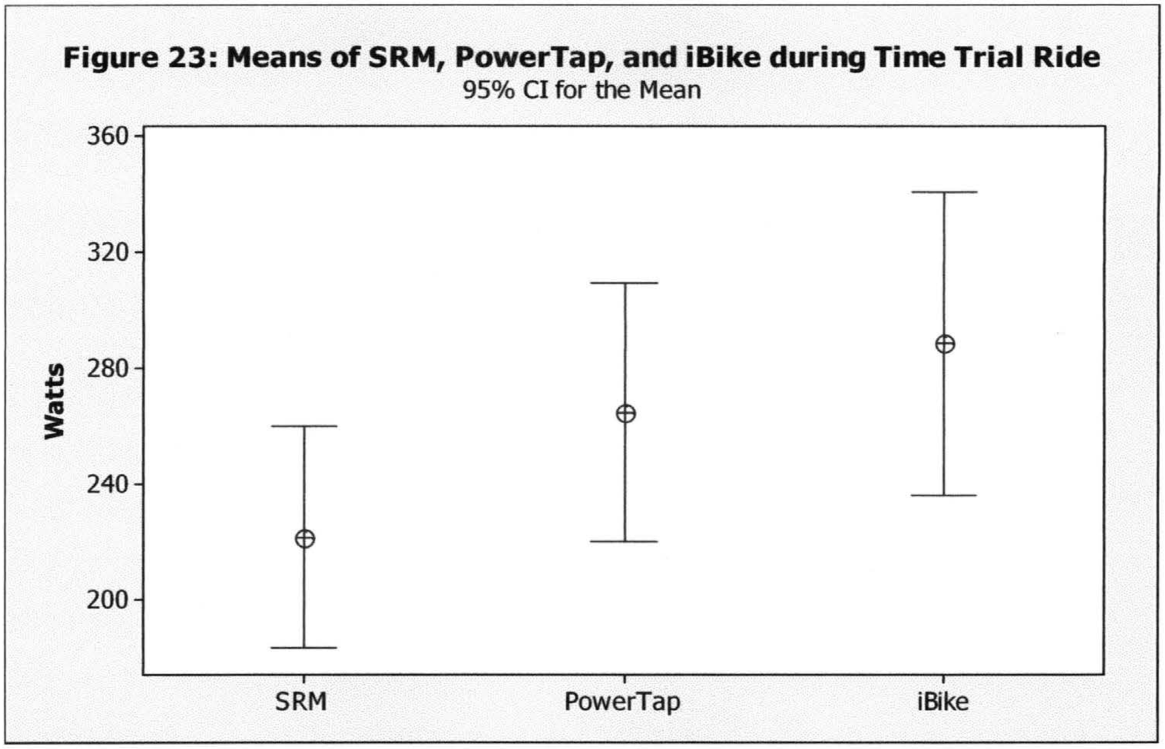

Figure 23. Means Power Outputs during Time Trial Trails. Shows a significant difference between all of the different power meters.

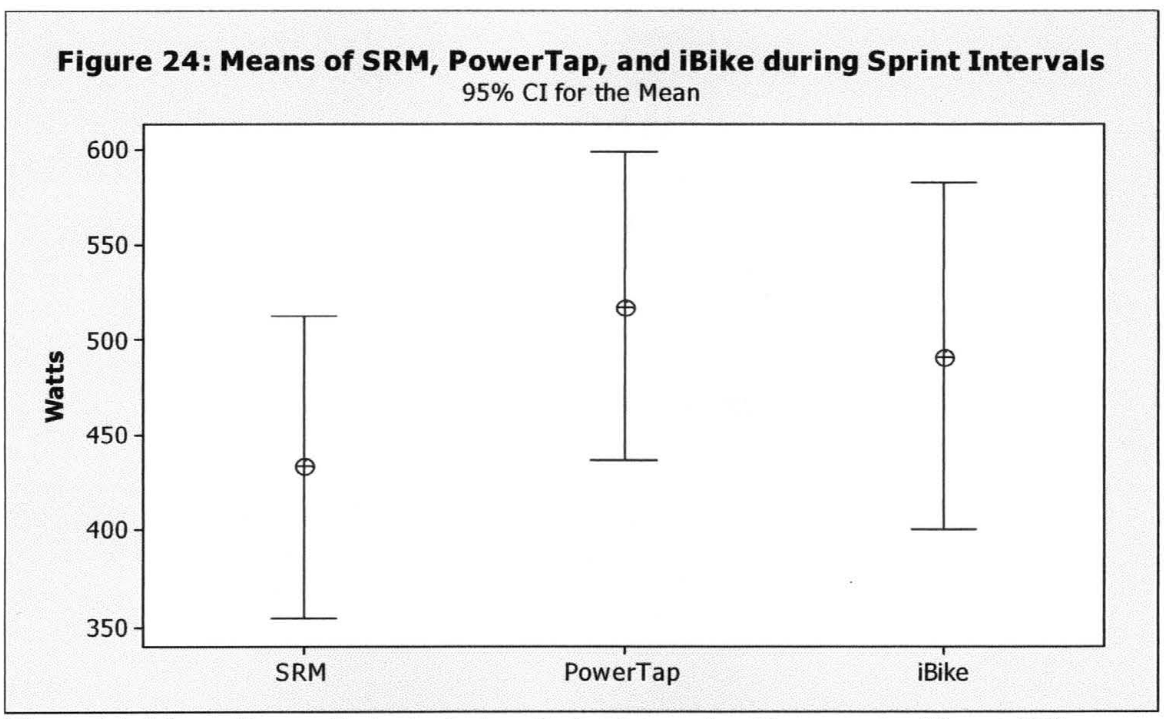

Figure 24. Means Power Outputs during Sprint Intervals. Shows a significant difference between the SRM and both the PowerTap and iBike, but not a significant difference between the PowerTap and iBike.

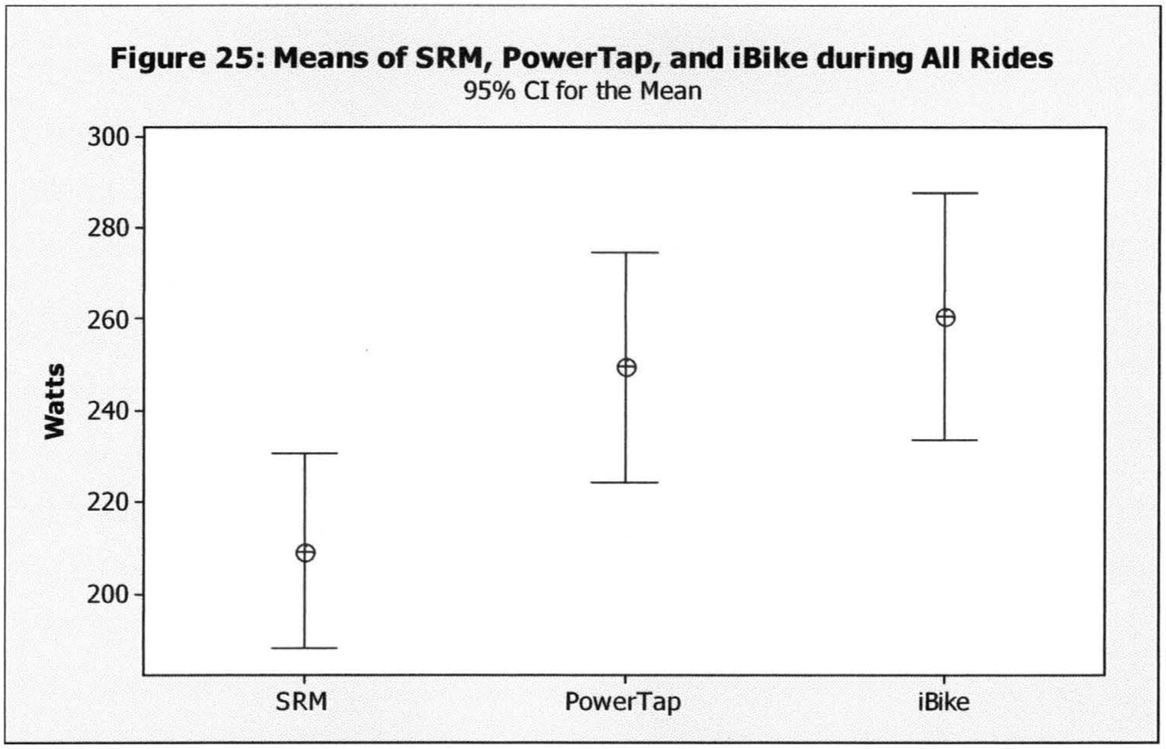

Figure 25. Means Power Outputs during All Trials. Shows a significant difference between all of the different power meters.

CHAPTER V

DISCUSSION

This study is the first attempt to compare the iBike pro power meter to the SRM and PowerTap power meters. Both the SRM and PowerTap power meters have been shown to be valuable instruments for measuring power output (15), and therefore were used as a basis for comparison. In addition, this study allowed for further comparison of the SRM with the PowerTap. The correlations among these three different power meters were very high. This is a strong indicator that they are closely measuring the same power.

The reason a comparison between these devices is necessary is because the iBike pro measures power in a very different way than either the SRM or PowerTap. The SRM power meter measures power using strain gauges in the crank. In this manner it is able to measure torque directly, and convert that torque into a power reading. Similarly, the PowerTap power meter also measures torque using strain gauges, but instead the strain gauges are built into the rear hub of the bike. Therefore, similarly to the SRM, the PowerTap uses the torque to obtain power measurements. The real difference in ways of acquiring power can be seen when looking at the method the iBike pro uses for calculating power.

The iBike pro has no direct way of measuring torque, and therefore power. Instead, the iBike pro uses the combination of: speed of the bicycle; wind speed; combined weight of the cyclist, their bicycle, and all of their gear; grade (elevation changes up or down), and a coast down feature that adjusts for the wind resistance of the cyclist. Based on all of these factors the iBike pro is able to calculate power, without actually measuring torque.

Before comparing the iBike pro to the SRM and PowerTap, it was first necessary to compare the SRM and PowerTap to each other. Previous studies have found that the SRM measures power output relatively accurately (3, 15, 22, 32). Similarly, the PowerTap has been shown to be a valuable instrument for measuring power (15), and is presently being used by elite cycling coaches such as Joe Friel and Chris Carmicheal to create power based training programs (14, 18). Therefore, since both the SRM and PowerTap measure torque directly, and both have been shown to be valuable tools for measuring power (15), it is important to consider how they coincide in this study.

Based on an examination of the means for all of the trials preformed in this study, the SRM consistently recorded lower means for power output than the PowerTap. This is similar to the findings in a previous study that showed that the SRM power meter measured consistently lower than the PowerTap power meter by 4.8% (15). However, the previous study's average difference of 4.8% between the SRM and PowerTap is much lower than this study which showed an average difference of 19.1% between the SRM and PowerTap. Table 2 shows the differences between the SRM and PowerTap during all of the trials. The difference from trial to trial varied from 37.8 watts during the hill climb to 42.9 watts during the time trial. However, the variation was relatively consistent from trial to trial, which may mean that the SRM and PowerTap were measuring the same thing. Nevertheless, the SRM and PowerTap were consistently different from each other by a certain amount, in this case, approximately 40 watts.

Even though the means obtained for the SRM and PowerTap were very different in this study, the correlation between the SRM and PowerTap were extremely high (see Table 1). These extremely high correlation values show that even if the SRM and PowerTap were not measuring the exact same values for power output they were likely measuring the same factor. Looking at the slopes, lines of best fit, and lines of identity in Figures 6, 9, 12, 15, and 18, there are some definite trends between the SRM and PowerTap. First, the slopes of all of the trials are above one, indicating that the power output for the PowerTap is higher than the SRM as power increases. This indicates a consistent disagreement between the SRM and PowerTap. Second, the line of best fit is slightly closer to the line of identity at lower power output and slightly farther away at higher power outputs (this is very visible in Figure 18). This means that the PowerTap is measuring even slightly higher power outputs on the higher end of the range of power outputs than the SRM. This is similar to what was found in a previous study that showed that the PowerTap was 4.8% higher on average, but was 7.8% higher at max power output (15), so that as power increases there is an increase in the variation between the SRM and PowerTap.

Table 2 shows the means of the iBike and the SRM during all of the different trials. Table 3 illustrates that there were significant differences between the SRM and iBike during all of the various trials. The iBike was on average 51.2 watts higher than the SRM when looking at all of the data obtaining during the three different trials. This difference is similar to the difference between the SRM and PowerTap, which have already been shown to be measuring the same factor, even if they are not measuring the same wattage.

The iBike was not significantly different from the PowerTap during most of the trials (see Table 3). The iBike and PowerTap were not significantly different during the hill climb, training ride, or sprint interval, but were significantly different during the time trial and overall trials combined. Possible reasons for the means of the iBike and PowerTap being similar on all trials except for time trial and overall may be that during the time trial where intensity is the highest there is the most variation in environmental factors. This variation in environmental factor causes the iBike to record higher than expected values for power. This could be the reason the iBike recorded 23.8 watts higher than the PowerTap during the time trial tests. Essentially the high intensity of a time trial ride may have caused increased vibration of the iBike and changes in environmental factor such as the wind and tilt measured by the iBike.

The correlations between the iBike and both the SRM and PowerTap were high, but not as high as the correlations between the SRM and PowerTap to each other (see Table 1). However, on the hill climb trial the correlation between the iBike and the other two power meters was extremely high. A possible explanation could be that the environmental factors that affect the iBike are limited by: the slow speed of ascent, the decreased variation in wind speed, the decreased vibration while climbing, and the fact that all of the power meters readily went to zero during the decent portion of the trial. Conversely, the other trials included more variation in speed, vibration, terrain, and wind speed that may have caused the iBike to be less highly correlated to the SRM and PowerTap during the training ride, time trial, and sprint intervals.

The scatterplots of the iBike compared to the SRM illustrated several important points. Figure 8, which represents the hill climb trials, shows that the line of best fit is almost identical to the line of identity except that the slope of the line of best fit is slightly below the line of identity. Similar to the scatterplot data comparing the iBike to the SRM is the scatterplot data comparing the iBike to the PowerTap. Figure 7, which represents the hill climb trials, shows that the line of best fit is almost identical to the line of identity between the iBike and PowerTap. These two cases demonstrates again that the iBike is very accurate on a hill where environment factors, such as speed, wind, tilt, and vibration are unlikely to affect the iBike's precision. Conversely, Figures 11, 14, 17, and 20, which represent a comparison between the iBike and SRM on the training ride, time trial, sprint intervals, and all data combined respectively, have lines of best fit slightly higher on the lower end and slightly lower on the high end when compared to the lines of identity. This is also the case when looking at Figure 10, 13, 16, and 19, which represent the same rides for the iBike compared to the PowerTap. Therefore, it is likely that the iBike loses accuracy and gives higher than expected values for power output at the higher end of possible power outputs. This again is likely caused by variations in the environment such as speed, wind, tilt, and vibration.

The results of this study have practical application in attempting to determine whether different power meters are consistent enough to be used as training tools. Currently several prominent cycling coaches, such as Joe Friel and Chris Carmicheal are using the PowerTap to develop training programs (14, 18), therefore it is important to show that power meters like the PowerTap obtain consistent data. Even if a power meter does not perfectly measure power, it is important that the data obtained are reliable. This is important because in order to train with power coaches need to be able to recognize changes that occur throughout training.

Based on the extremely high correlations between the SRM and PowerTap power meters in this study and the finding of previous research comfirming their accuracy (3, 15, 22, 32), it is likely that they are measuring consistent data. Even if they are not reporting the exact same value for power, the variations that exist between the SRM and PowerTap can be accounted for by adjusting by a factor. To the contrary, the iBike may be less consistent when compared to the SRM and PowerTap because of the large number of variables that are used by the iBike to calculate power. However, based on the high correlation between the iBike and both the SRM and PowerTap, it is likely that the iBike could be used for a power based training program. Nevertheless, coaches and exercise scientists should be cautioned about using the iBike or any power meter to determine very small changes in power output.

In addition to the importance of consistence, there is the issue of price of the various different types of power meters. The SRM is usually the most expensive starting at around $2,000 and going up to $4,000 depending on the make and model. The PowerTap is less, but still runs from around $1,000 to $1,700 and requires installation of the PowerTap hub into a rear rim, which increases the overall cost. The iBike pro is by far the cheapest, with the base model without cadence running $450 and the cadence package costing around $100 more. Therefore, since the iBike pro is at least half to as much as one-eighth of the cost of the SRM and PowerTap, it may be a good choice for beginning and recreational cyclists that are looking to training with power at a much reduced cost. However, for serious competitive and elite level cyclists that need more consistent measures of power output, it would be advisable to buy a PowerTap or SRM over the iBike pro. Based on the findings of this study and previous studies of the SRM and PowerTap (3, 15, 22, 32), they have been shown measure power in a more consistent manner than the iBike pro.

This study did have some limitations that may have affected some of the results. The study was limited by the use of only one particular iBike pro, one particular PowerTap, and one particular SRM. A previous study that looked at the SRM and PowerTap used several of each power meter, and found a certain amount of variation exist from power meter to power meter (15). In addition, the number of subjects was limited to eight for the experimental trials. More subjects would have increased the statistical power of the results of the study. The study was also limited by the number of coursed that could be ridden by each of the subjects. An increased number of courses and terrains may have identified additional inconsistencies between the different power meters. Lastly, the study was limited by the fact that the PowerTap and iBike pro were brand new, where as the SRM was several years old. This may be why even though the SRM and PowerTap were consistently highly correlated there means were significantly different.

Conclusions

1. The power outputs recorded by the iBike pro power meter were highly positively correlated to both the SRM and PowerTap power meters. This shows that even if the

iBike pro is not measuring the exact same power output as the SRM and PowerTap it is likely measuring the same factor.

2. The iBike pro power meter recorded higher power outputs than the SRM power meter, but did not record significantly higher power outputs than the PowerTap power meter during the radical hill climb and descent. The reason the iBike pro recorded higher power outputs than the SRM is likely because it consistently recorded higher power output on all of the trials. Conversely, the iBike pro recorded similar power outputs to the PowerTap during the hill climb and descent, likely because the hill limits environment factor because of lower speeds and decreased vibration. In addition, it was suspected prior to the study that the iBike pro would give power outputs during the descent portion (when power should go to zero because the cyclist is not pedaling) of the hill climb and descent, but it was shown that all of the devices readily went to zero during the descent portion of the hill climb and descent. The slow speed of ascent, decreased vibration, and the fact that the iBike pro went to zero during the descent are likely the reasons that the iBike pro and PowerTap recorded similar power outputs.
3. The iBike pro power meter did record higher power outputs than the SRM, but did not record higher power outputs than the PowerTap during an all out sprint. The reason the iBike pro recorded higher power outputs than the SRM is likely because it consistently recorded higher power output on all of the trials. The reason the iBike pro recorded power output slightly lower but not significantly different than the PowerTap is likely because the iBike pro is more accurate in a sprint than originally expected.

4. It was shown that the SRM power meter consistently recorded lower power outputs than the PowerTap power meter. This is similar to the findings in a previous study that showed that the SRM power meter measured consistently lower than the PowerTap power meter by 4.8% (15). However, the previous study's average difference of 4.8% between the SRM and PowerTap is much lower than this study which showed an average difference of 19.1% between the SRM and PowerTap.

Recommendations for Future Study

Based on the finding of this study and previous ones, it is important for exercise scientists to study bicycle-mounted power meters in the future. An area that needs additional study is the affect of power based training methods on cyclists. Currently many cycling coaches are creating power base training methods (14, 18), but how well these training methods work remains to be seen. In addition, many aspects of the iBike pro need to be further tested. First, the iBike pro needs to be further tested to determine the affect of head, tail, and cross winds on power outputs. There seemed to be some evidence, but none conclusive, in this study that the wind may be the main factor limiting the consistence of the iBike pro. Further testing of the iBike pro under various wind condition may clarify whether or not the wind affects the iBike pro's ability to record accurate power outputs. In addition, the iBike pro needs to be tested under road race conditions to see if drafting and turning affect performance. In road racing a rider usually spends a large portion of a race in the draft of other cyclists, so it is important to look at whether or not drafting affect the iBike pro's accuracy. Also, during criterium road racing, cyclists have to perform many tight turns on a short course, which may affect the performance of the iBike pro by changing the tilt of the bicycle. If the tilt of the bike is change the power output may be very different than expected. All of these issues need to be further studied by exercises scientists in the future in order to understand the efficacy of power based training programs and the accuracy of the iBike pro power meter.

APPENDIX

Original Data

Subject	Hill-SRM	Hill-PT	Hill-iBike	Train-SRM	Train-PT	Train-iBike
1	217.5	262	251.8	142.5	194	160.8
2	153.9	181	181.4	150.6	172	195.5
3	181.8	205	207.3	179.1	200	190.6
4	271.5	341	329.4	258.1	300	310.7
5	311.3	388	371.1	219.1	269	305.6
6	225.9	268	276.9	139.6	169	176.5
7	227.6	254	280.4	180	218	224.9
8	175	206	221.6	176.4	208	249

Subject	TT-SRM	TT-PT	TT- iBike	Sprint-SRM	Sprint-PT	Sprint-iBike
1	244.3	302	299.3	569.5	665	652.4
2	175.8	206	226.1	335.4	415	365.3
3	213.9	247	232.9	345.3	435	365.3
4	285.9	337	376.1	576.4	661	630.6
5	262.9	321	368.4	415.6	492	445.9
6	165.4	207	213.7	368.8	465	450.4
7	244.6	284	308.5	453.6	532	468.6
8	177	214	280.7	404.9	475	547.4

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