Journal of Sports Science 5 (2017) 235-241
doi: 10.17265/2332-7839/2017.05.001

Validity and Reproducibility of the Garmin Vector Power Meter When Compared to the SRM Device

Randolph Hutchison[1], Gibson Klapthor[2], Karlee Edwards[1], Kaitlin Bruneau[1], Gregory Mocko[3] and Ardalan Vahidi[3]

1. Department of Health Sciences, Furman University, Greenville, SC 29613, USA

2. College of Medicine, Medical University of South Carolina, Columbia, SC 29425, USA

3. Department of Mechanical Engineering, Clemson University, Clemson, SC 29634, USA

Abstract: Mobile power meters allow for cyclists to monitor power output (PO) during training and competition. The Garmin Vector power meter (VPM) measures PO at the pedal compared to the crank and has been tested in only a few limited studies. The purpose of this study was to determine the validity and reproducibility of the VPM by comparing it to the SRM. The VPM validity was tested by (1) a submaximal incremental test, (2) submaximal constant power test, (3) sprint test, and (4) a field test. The reliability of the VPM was tested by repeating the laboratory tests 10 times over a 6 week span. Significant differences (P = 0.046) were found between the mean PO_{SRM} (178 ± 1.8 W) and PO_{VPM} (163.5 ± 14.7 W) for the submaximal constant-power test. No significant differences were found between the PO_{MAX} SRM and the PO_{MAX} VPM. The reproducibility of the VPM was lower than the SRM (CV = 8.52 ± 4.0 vs 3.48 ± 1.9, 10.66% vs 5.50%, and 67.7% vs 55.3% for the submaximal incremental test, submaximal constant-power test, and field test respectively). The PO_{VPM} appears to underestimate the PO_{SRM} and is less valid and reliable across various cycling efforts.

Key words: Mobile power meters, power output, SRM, VPM, submaximal incremental test, submaximal constant power test, sprint test, field test.

1. Introduction

The development of mobile power meters (e.g.: SRM, Garmin Vector (VPM), PowerTap (PT)) has allowed cyclists to track their power output (PO) while both training and competing. These power meters can be used outdoors or indoors when coupled with trainers such as a CompuTrainer (CT) or Velotron Cycle Ergometer. With indoor trainers accessible and commonly used, many cyclists now base their training regimens on PO. Thus, determining the validity and reproducibility of power meters is important for cyclists to accurately establish their workloads and monitor their progress. If discrepancies are found in a product's ability to accurately measure PO, cyclists are able to account for this and determine how to optimally utilize the device in their training, both indoors on trainers as well as outdoors in the field.

Some power meters have previously been studied to test their validity and reproducibility [1, 2]. However with the high number of power meters on the market, many have yet to be tested. The VPM is one such power meter that is novel to the market in that it determines power from the pedal, compared to the crank or rear hub as in other devices. The VPM offers several other advantages over other mobile power meters. They are competitively priced in comparison to other high end power meters, and the pedals can easily be switched back and forth between bikes. Because the strain gauges independently measure force in both pedals, the VPM offers the capability of analyzing power differences between the left and right sides. This is a feature that few other power meters offer. Ultimately though, the most important function of a power meter is to provide a valid and reproducible PO.

The crank-based SRM has proven to be the choice

Corresponding author: Randolph Hutchison, Ph.D., assistant professor, research fields: biomechanics, human performance, exercise science.

for comparison between mobile power meters due to its high degree of accuracy, validity, and repeatability and was chosen for comparison purposes for this study [3-6]. To our knowledge, the VPM has only been tested for its validity and reproducibility in less traditional settings without extensive field testing [6, 7]. Thus, this study was done to determine the validity and reproducibility of the VPM by comparing it to the SRM on more traditional methods using a stationary ergometer.

2. Methods

2.1 Subjects

A male Category 1 cyclist and collegiate national champion (age 20 yrs, height 1.755 m, body mass 65 kg) volunteered to participate in the study. Prior to the test, the subject gave written informed consent that was approved by the Institutional Review Board. The subject underwent 10 testing sessions over a 6-week period with each testing session comprised of three separate laboratory testing protocols. All three tests were performed on the CT described below. After the laboratory testing was complete, the subject also completed a 3-hour field test.

2.2 Instrumentation

All tests were conducted with the same road racing bicycle that was equipped with Garmin Vector power meter pedals as well as the crank-based Road SRM Science power meter. The VPM pedals contain eight silicon strain gauges within each spindle. The SRM contains 20 strain gauges, and the manufacturer (SRM, Jülich, Welldorf, Germany) guarantees an accuracy of ± 0.5%. The most up to date firmware was used for both power meters. Data from the VPM and SRM was wirelessly transmitted via ANT+ protocol to the Garmin Edge 500 and the PowerControl VII head units, respectively. An electromagnetically braked Racermate CompuTrainer Lab (Racermate, Seattle, WA) was used to administer all indoor lab testing.

2.3 Protocols

For the purposes of comparison to previous literature, the validity and the reliability of the VPM ergometer was tested using protocols derived from those used in previous studies [1, 2, 6]. Through four different tests, we compared PO_{VPM} and PO_{SRM} using different gear ratios, outputs of power, pedaling cadences, and posture to test validity, while repeating the three lab tests 10 times and conducting one field test to demonstrate reproducibility. The laboratory tests included: a submaximal incremental test, a submaximal constant power test, and a sprint test. All three lab tests were performed on the CT. The subject performed all three lab protocols in the same day for each day of lab testing. Ten days of lab testing were completed over a six-week period. There was at least a 5-minute break between each test. The temperature of the laboratory was maintained at 21℃. In addition, one 3-hour field test was done to assess the overall validity of the VPM.

Before each laboratory test, the bike was attached via the quick release skewer of the rear wheel and the rear tire was cleaned with an alcohol pad and inflated to 6.9 kPa. The CT was calibrated and the press-on force was set according to the manufacturer’s recommendations. The VPM was installed per manufacturer’s recommendations and a static zero calibration, including a torque “zero offset”, was performed on both the SRM and VPM before each test.

2.3.1 Indoor Tests

The subject performed three laboratory tests each session. These tests included a submaximal incremental test, a submaximal constant-power test, and a sprint test. These three tests were repeated 10 times over a time period of 6 weeks. All three lab tests were performed on a CT ergometer (CompuTrainer, Seattle, Washington).

2.3.2 Submaximal Incremental Test

The submaximal incremental test was performed with the subject riding at 6 different PO (100, 165, 175, 230, 280, and 395 W). At each PO, the subject rode in three different gear ratios (39/15, 39/19, and 39/24). Over the course of the 18 intervals, 6 different cadences were used (47, 60, 75, 80, 100, and 123 RPM). These POs and cadences were used to cover a broad spectrum and to allow for comparisons to previous literature [1, 2, 6]. All 18 trials were performed in the seated position; however, the subject also performed one standing trial with a PO of 160 W in 39/19 to determine the effect of pedaling posture on PO. All of the trials lasted one minute each for a total of 19 one minute trials (6 PO × 3 gear ratios + 1 standing trial) and were performed in random order with 3 minutes recovery in between.

2.3.3 Submaximal Constant-Power Test

To study the validity of the VPM over a longer period of time, a 30-minute constant power test was performed. The test was completed in the seated position with a PO of 170 W. The subject rode in a gear ratio of 39/15 and at a pedaling cadence of 85 RPM.

2.3.4 Sprint Test

To study the validity of the VPM at maximal POs, a sprint test was conducted. The test was a series of 4 all out sprints of 8 seconds done from the seated position. The subject rode in four different gear ratios (53/14, 53/15, 53/17, and 53/21). Between each sprint, there was a 5-minute active recovery period at ~150 W. Before each sprint the subject dropped his pedaling cadence to below 40 RPM. The PO_{MAX} was the maximal PO recorded from each sprint. During the sprints the magnetic resistance of the CT was set at minimal resistance (1 W).

2.3.5 Field Test

In addition to the three laboratory tests, a three-hour field test was conducted. The test was done on roads of varying conditions simulated during lab testing including varying slopes, pedaling cadences, and pedaling postures (seated and standing).

3. Statistical Analysis

Pedaling cadence and PO were stored every 0.5 seconds on the SRM PowerControl 7 for the SRM and every second on the Garmin Edge 500 for the VPM. The power and cadence data from the submaximal incremental trials were averaged over one minute for each interval and the power and cadence data from the submaximal constant power test were averaged over 5 minutes. For the sprint test, the SRM power data were averaged over one second for comparison to the VPM.

The data from all of the tests was tested for normality and homogeneity of variance and the data was not normally distributed. Thus, for the analysis of differences, non-parametric Wilcoxon Tests were used. For the submaximal constant power test, time effects and cadence effects on PO were tested with a related samples Friedman's analysis of variance by rank.

Correlation between the two power meters during the submaximal incremental tests were analyzed using Spearman's correlation coefficient (r). In addition, based on the recommendations of Atkinson and Nevill [8], 95% limits of agreement (LOA) were calculated based on the methods of Bland-Altman [9] so that 95% of the differences between two power meters lie between the mean bias ± (standard deviation (SD) * 1.96). To determine the 95% LOA from the submaximal incremental test Bland-Altman plots were used and these data were then checked for heteroscedasticity by calculating the correlation between the absolute differences of the PO_{SRM} and PO_{VPM} and the mean PO of the 2 devices as recommended by Atkinson and Nevill [8] (r = 0.2744, P = 0.002). This analysis revealed that there was positive heteroscedasticity. Therefore, the data were logarithmically transformed as recommended (Fig. 1) [8] and the differences of the natural log power measurements were used to establish the mean bias and the 95% LOAs were calculated. The 95% confidence intervals (CI) for the mean bias were also calculated.

The reliability of the VPM was analyzed by assessing the coefficient of variation for the submaximal incremental tests and submaximal constant power tests. Data for the submaximal incremental tests are presented in the table as mean percent ± SD (Table 1). The CV for the submaximal

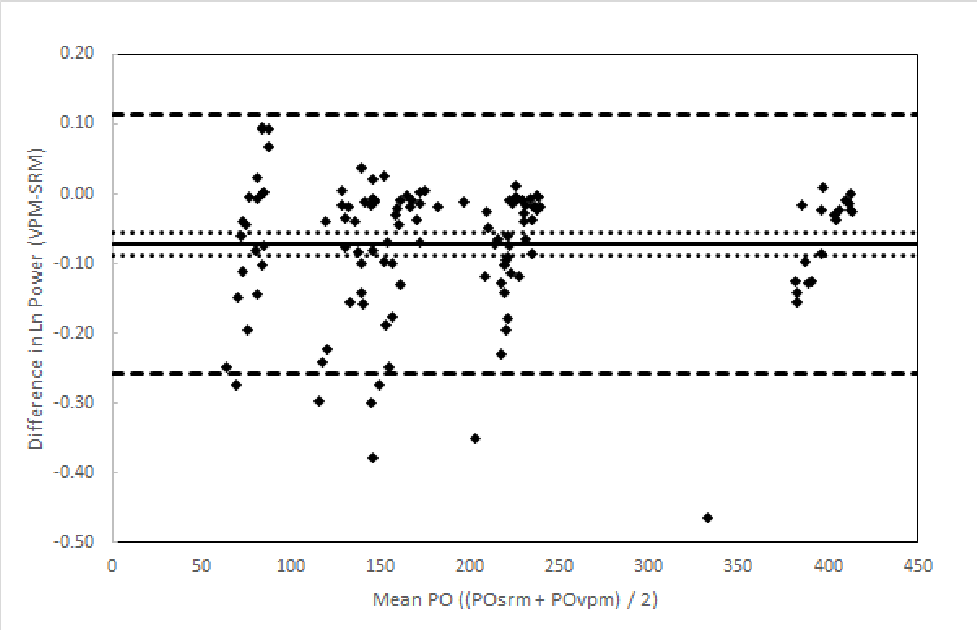

Fig. 1 Bland-Altman Plot. Bias (center line), limits of agreement (inner dashed lines), and 95% confidence interval (outer dashed lines) obtained with Bland-Altman analysis for the comparison between the power outputs (PO) measured on the Vector Power Meter and SRM power meter for submaximal incremental tests.

constant power tests was calculated as a means for the entire test.

4. Results

4.1 Validity

4.1.1 Submaximal Incremental-Power Tests

There was a strong positive correlation (r = 0.956, $P < 0.001$) between the PO_{SRM} and the PO_{VPM} during the submaximal incremental-power tests. The ratio limits of agreement from the PO differences were 0.930 ×÷1.204. The 95% confidence interval of the mean bias was 0.915 - 0.946 (Table 1). So, the certainty of the VPM would be interpreted as: If VPM = 100 W, 95% of the data would be between 100 * 0.930 * 1.204 and 100 * 0.930/1.204, or 112 Watts and 77 Watts. The mean and SD for the one minute intervals were 191 ± 95 W and 205 ± 101 for the PO_{VPM} and the PO_{SRM} respectively. The mean bias was 14.0 ± 20.0 W, which is a difference of 6.8 ± 8.3%. Wilcoxon tests showed that for 11 of the 19 intervals the VPM was significantly different from the SRM ($P < 0.05$). A Friedman's analysis of ranks showed there were no significant effects of cadence on power (Table 1).

4.1.2 Submaximal Constant-Power Tests

There were significant differences ($P = 0.046$) between the mean PO_{SRM} (178 ± 1.8 W) and PO_{VPM} (163.5 ± 14.7 W). The Friedman test was run on the VPM 5-minute average PO to test for time effects on PO. There was no variation with time for the 5-minute intervals with exception of the first interval and the fifth ($P = 0.03$).

4.1.3 Sprint Tests

There were no significant differences between any of the four gear ratios (Fig. 2). On average the VPM underestimated PO_{MAX} by 9.6% in comparison to SRM PO_{MAX} (range: 2.4% to 17.1%).

4.1.4 Field Test

During the field test, the VPM underestimated the mean PO by 14.6% (PO_{VPM} 175 ± 118 W, CV = 67.7% vs. PO_{SRM} = 205 ± 113 W, CV = 55.3%); however, this difference was not significant ($P = 0.317$).

4.2 Reliability

See table for the mean CVs for the submaximal incremental tests. The mean CVs at 100 W, 165 W, 175

Table 1 Comparison of the VPM and SRM for Submaximal One-Minute Incremental Power Tests.

Position	Gear Ratio	Set Power	Set Cadence	Cadence (SRM)	Mean PO VPM (W)	Mean PO SRM (W)	VPM CV (%)	SRM CV (%)
Seated	39/15	100	47	50 ± 2	79 ± 7	81 ± 5	8.93	6.34
	39/19	100	60	62 ± 2	78 ± 8	81 ± 4	10	5.51
	39/24	100	75	76 ± 2	74 ± 12	80 ± 4	16.67	4.86
	39/15	165	80	80 ± 2	156 ± 12*	168 ± 3	7.57	2.07
	39/19	165	100	100 ± 2	149 ± 19*	169 ± 5	12.52	2.78
	39/24	165	123	122 ± 2	159 ± 21*	174 ± 7	13.46	4.21
	39/15	175	47	50 ± 2	145 ± 9	150 ± 8	6.44	5.42
	39/19	175	60	62 ± 3	142 ± 6	148 ± 9	4.29	6.4
	39/24	175	75	76 ± 2	134 ± 10	143 ± 8	7.78	5.91
	39/15	230	80	80 ± 1	222 ± 12*	235 ± 4	5.54	1.86
	39/19	230	100	99 ± 3	217 ± 18*	240 ± 2	8.13	0.91
	39/24	230	123	121 ± 2	218 ± 26	237 ± 2	11.73	0.91
	39/15	280	47	47 ± 3	210 ± 8*	220 ± 11	3.98	4.85
	39/19	280	60	61 ± 3	223 ± 8*	232 ± 7	3.49	3.15
	39/24	280	75	75 ± 2	213 ± 12*	227 ± 6	5.6	2.72
	39/15	395	80	80 ± 3	387 ± 18*	409 ± 5	4.65	1.25
	39/19	395	100	98 ± 2	383 ± 20*	410 ± 9	5.28	2.23
	39/24	395	123	123 ± 3	365 ± 58	408 ± 6	15.8	1.55
Standing	39/19	160	60	60 ± 1	116 ± 12*	131 ± 4	10.14	3.1
Mean							8.53 ± 4.0	3.48 ± 1.9
Confidence Interval							6.6-10.5	2.6-4.4

*Significant difference between VPM and SRM ($P < 0.05$).

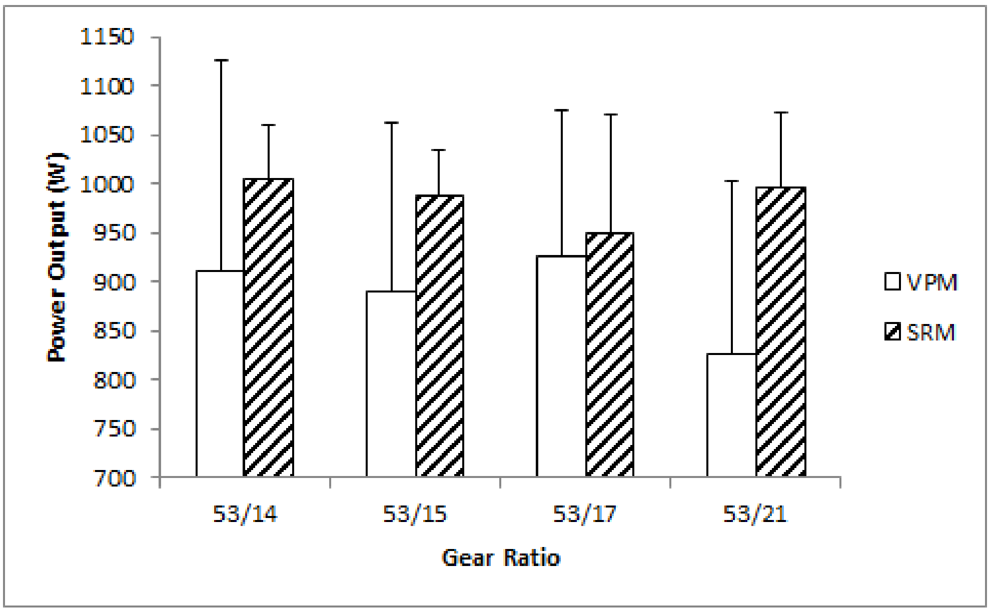

Fig. 2 Vector Power Meter and SRM power output during maximal exercise tests with low, middle, and high gear ratios. No significant differences for power output maximum between the SRM power meter and the Vector Power Meter.

W, 230 W, 280 W, and 395 W were 11.9% vs. 5.6%, 11.2% vs 3.0%, 6.2% vs 5.9%, 8.5% vs. 1.2%, 4.4% vs 3.6%, 8.6% vs 1.7% for PO_{VPM} and PO_{SRM} respectively. For the submaximal constant power test the mean CV was 10.7% and 5.5% for the PO_{VPM} and PO_{SRM}, respectively.

5. Discussion

5.1 Validity

The purpose of this study was to determine the validity and reproducibility of the pedal-based Garmin VPM by comparing it to the scientific model of the SRM crank power meter. This study demonstrated that while the VPM was not significantly different during PO_{MAX} sprints, the VPM underestimated power output during submaximal incremental power as well as submaximal constant-power tests when compared to the SRM. A strong positive correlation (r = 0.956) was established between the PO_{SRM} and the PO_{VPM} during the submaximal incremental power tests. However, the VPM measured significantly lower power for 11 of the 19 intervals in the submaximal incremental power tests as well as significantly lower mean PO_{VPM} compared to the mean for PO_{SRM} submaximal constant-power tests. Additionally, significant differences were not observed for the field test.

This study demonstrates both similarities and differences to previous studies comparing the VPM to the SRM. Novak and Dascombe [6] studied 21 male cyclists and while there were large variances for 5 second maximal effort sprints, similar to our results no significant differences were found. However, Bouillod et al. [7] found significantly lower power output for the VPM in the 53/19 gear ratio. Over a variety of maximal effort sprints between 5 and 600 seconds, Novak and Dascombe [6] found the VPM overestimated power output. This is contrary to a majority of our findings for the submaximal incremental tests as well as the submaximal constant-power tests. This difference may be due to the maximal effort versus constant effort testing protocols. Bouillod et al. [7] did not find significant differences during constant power tests, but used a cycling treadmill versus more traditionally accepted cycling trainers and varied wattages by adding weight via water bottles to the cyclist's bicycle. This may signify the VPM is not universally similar to the SRM in all conditions.

5.2 Reliability

In contrast to other studies [6-7] with self-selected gearing, our methods included traditionally used cycling ergometers as well as a three-hour field test. The reproducibility of the VPM was lower than the SRM (CV = 8.52 ± 4.0 vs 3.48 ± 1.9, 10.66% vs 5.50%, and 67.7% vs 55.3% for the submaximal incremental test, the submaximal constant power test, and the field test respectively). Similar to Novak and Dascombe [6], we also observed a large variability in the PO_{MAX} exercise test with no significant difference between the SRM and VPM. Including all conditions, the coefficient of variation tended to be higher in the VPM.

6. Conclusion

The Garmin Vector pedal power meter offers advantages over other crank or hub based power meters due to the competitive pricing and independent measurement of power in each pedal. However, the VPM appears to be less valid and reliable than the SRM for measures of power output across various cycling efforts. Although the Garmin Vector pedal power meter offers advantages in terms of cost and ease of installation, caution should be taken due to larger variances and underestimation of power in certain instances.

References

[1] Bertucci, W., Duc, S., Villerius, V., Pernin, J. N., and Grappe, F. 2005. "Validity and Reliability of the PowerTap Mobile Cycling Powermeter When Compared with the SRM Device." *International Journal of Sports Medicine* 26 (10): 868-73.

[2] Duc, S., Villerius, V., Bertucci, W., and Grappe, F. 2007. "Validity and Reproducibility of the Ergomo pro Power Meter Compared with the SRM and Powertap Power Meters." *International Journal of Sports Physiology and Performance* 2 (3): 270.

[3] Balmer, J., Bird, S. R., Davison, R. C. R., Doherty, M., and Smith, P. M. 2004. "Mechanically Braked Wingate Powers: Agreement between SRM, Corrected and Conventional Methods of Measurement." *Journal of Sports Science* 22 (7): 661-7.

[4] Gardner, A. S., Stephens, S., Martin, D. T., Lawton, E.,

Lee, H., and Jenkins, D. 2004. "Accuracy of SRM and Power Tap Power Monitoring Systems for Bicycling." *Medicine and Science in Sports and Exercise* 36 (7): 1252-8.

[5] Jones, S. M., and Passfield, L. 1998. "The Dynamic Calibration of Bicycle Power Measuring Cranks." In *The Engineering of Sport*, edited by Haake, S. J. Oxford, Blackwell Science, 265-74.

[6] Novak, A., and Dascombe, B. 2016. "Agreement of Power Measures between Garmin Vector and SRM Cycle Power Meters." *Measurement in Physical Education and Exercise Science* 20 (3): 167-72.

[7] Bouillod, A., Pinot, J., Soto-Romero, G., Bertucci, W., and Grappe, F. 2016. "Validity, Sensitivity, Reproducibility and Robustness of the Powertap, Stages and Garmin Vector Power Meters in Comparison with the SRM Device." *International Journal of Sports Physiology and Performance* 14: 1-26. [Epub ahead of print]

[8] Atkinson, G., and Nevill, A. M. 1998. "Statistical Methods for Assessing Measurement Error (Reliability) in Variables Relevant to Sports Medicine." *Journal of Sports Medicine* 26 (4): 217-38.

[9] Bland, J. M., and Altman, D. G. 1986. "Statistical Methods for Assessing Agreement between Two Methods of Clinical Measurement." *Lancet* 327 (8476): 307-10.