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Accuracy in measurement of elevation gain in road cycling

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Accuracy in measurement of elevation gain in road cycling

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Abstract

Accurate measures of elevation gain are important for monitoring energy expenditure and physical load. The aim of this study was to determine the accuracy of barometric devices used for measuring elevation gain. Observational validation study. Twenty-eight barometric altimeter devices (SRM and Garmin) were used to measure total elevation gain during cycling over three different climbs (length range: 3.2-18.4 km), giving a total of 216 climbs. An online mapping tool (http://www.freemaptools.com/elevation-finder.htm) was used to calculate the criterion measure of total elevation gain. Data were categorised into two weather conditions: dry and wet. The standard errors of the estimate for total elevation gain measured by SRM and Garmin devices were 1.5% and 1.9%, respectively. In dry conditions, SRM devices underestimated the total elevation gain by an average of ~5% while the Garmin devices underestimated it by ~2%. In wet weather conditions the bias worsened to -25%. Measurements of total elevation gain recorded with devices of differed brands were similarly accurate in dry weather conditions. Wet weather conditions significantly decreased the accuracy of total elevation gain measurements.

Keywords observational validation study; training load; barometric altitude; portable measurement systems; performance analysis

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Introduction

The use of fitness tracking devices is widespread among active people and athletes (Cummins et al. 2013; de Magalhaes et al. 2015; Lee and Finkelstein 2014). In outdoor activities such as cycling, running and hiking; total elevation gain (TEG) and total distance covered significantly contribute to the total physical load (di Prampero et al. 1979; Hannas and Goff 2005; Perrin et al. 2000). It has been shown both in cycling and running that climbing one vertical meter is energetically equivalent to covering approximately 8 to 10 meters in a horizontal plane (Scarf 2007; Scarf and Grehan 2005). This emphasises the impact of vertical excursion on outdoor activities such as road cycling and therefore the need for valid and reliable measures of the TEG.

Barometric altimeters are commonly used in commercial devices to measure elevation changes, and subsequently to calculate TEG. A recent investigation showed good consistency in the measures of elevation gain recorded with commercially available devices, when they were used with similar settings (Menaspà et al. 2014). However, no known studies have investigated the validity of such devices. Therefore, the aim of this study was to determine the accuracy of barometric devices typically used for measuring elevation gain in road cycling.

Materials and methods

A validation study was performed to assess the accuracy of measuring TEG using different barometric altimeter devices used by road cyclists during training and racing. Twenty-eight devices were used in this investigation: 15 PowerControl7 (SRM PC7, Schoberer Rad Mebtechnik, Julich, Germany) and 13 Edge (Garmin International, Olathe, KS, USA), all updated to the most recent firmware available. Devices were mounted on the bicycle handlebars or on the stem as per manufacturer instructions. All the devices were set according to the manufacturers' recommendations: SRM PC7 were set to record data at 1 hertz, while the 'smart recording' setting was used with the Garmin Edge devices.

Three climbs were selected to test the devices' accuracy over a wide range of elevation gains. Climb A had a TEG of 160 m and was 3.2 km in length; Climb B had a TEG of 245 m and was 4.4 km in length; and Climb C had a TEG of 1045 m and was 18.4 km in length. A common characteristic of the selected climbs was that there were no downhill sections between the start and end points, so that the TEG corresponded to the difference between the altitude at the lowest and highest point of the climbs. The minimum and maximal altitudes used to calculate the criterion measure of TEG were determined using an online mapping tool (http://www.freemaptools.com/elevation-finder.htm).

The barometric devices were mounted on bicycles that were ridden a combined total of 216 times (Climb A; n = 112; Climb B; n = 68 and Climb C; n = 36).

All participants uploaded and shared their files online (http://www.trainingpeaks.com). In order to simulate every-day use and to make this study's results ecologically valid, the trials were performed at different times of the day and with different weather conditions (temperature range: 7 - 38 °C) during cycling training sessions and races. Due to the effect of changes in weather conditions on barometric pressure and consequently on measures of altitude, for the statistical analysis, TEG data were categorised based on weather conditions as 'dry' (n= 194) or 'wet' (n= 22). Conditions were categorised as dry where there was no rain and the skies were relatively clear for the duration of the climb. Conditions were categorised as wet where the skies were both overcast and it was raining for the duration of the climb.

Descriptive statistics are shown as mean (90% CI). Validity was determined using a similar process to Petersen et al. (2009) and in accordance with the recommendations of Pyne (2008). Specifically validity was assessed using the standard error of the estimate (SEE), which was calculated as the standard deviation (with 90% confidence interval [CI]) of the percentage error for each brand of device. Measurement bias was calculated by subtracting the criterion TEG from the TEG measured with barometric altimeters and subsequently dividing the difference by the criterion TEG. This research was conduct in agreement with International Ethics standards as described by Harriss and colleagues (2011). This study follows the guidelines of the Australian National Statement on Ethical Conduct in Human Research and was approved by the Australian Institute of Sport Ethics Committee.

Results

All data for both devices were normally distributed. The mean TEG recorded by the SRM PC7 in dry conditions was 151.4 m (150.8, 152.0), 231.2 m (230.4, 232.1) and 1003.7 m (998.2, 1009.2) for Climbs A, B and C respectively. The mean TEG recorded by the Garmin Edge units in dry conditions was 158.0 m (157.6, 158.4), 233.6 m (232.7, 234.6) and 1013.4 m (1006.5, 1020.3) for climbs A, B and C respectively. The standard error was similar between devices and between climbs of different elevation (table 1).

Table 2 reports the percentage bias of TEG measured by the devices compared to the criterion. When the devices were used in wet conditions, SEE and percent bias worsened considerably to 5.1% (4.1-6.9) and -25.4% (-24.0, -26.8), respectively

Discussion

This is the first study to assess the accuracy of measures of elevation gain recorded by commercially available devices used in road cycling. The elevation change is meaningful in determining the physical load experienced during physical activities or sports practice; however, previous research was limited to a single study reporting good consistency of the measures when devices of the same brand were used with similar settings (Menaspà et al. 2014). The present investigation reports the accuracy of commercially available devices, showing standard errors of the estimate lower than 2.0% for both SRM and Garmin devices (Table 1). Table 2 describes the underestimation of the total elevation gain by SRM (~5%) and Garmin (~2%) devices. Overall, the results of this study suggest that total elevation gain measured using barometric altimeters are accurate over a wide range of total elevations. Interestingly, a small sub-sample indicates that the measures of elevation gain recorded by the same devices in wet weather conditions are considerably worsened. Errors for TEG could be expected to result in similar errors for estimates of energy expenditure or training load assuming other metrics such as power output are not being utilised. Errors in the estimates in the range ~2-3% may well be considered negligible and in the range of other devices used to estimate energy expenditure such as SRM Powermeters (Gardner et al. 2004). Anything greater than this would likely result in substantial differences in the quantification of trainload or energy expenditure and so, certainly caution is warranted when using these devices for these purposes in wet or possible heavily overcast conditions.

This study provides initial insight into the accuracy of TEG measures over single climbs, future research

Table 1. Standard error of the estimate (standard deviation of the percentage error to known TEG with the 90% confidence interval) for Total Elevation Gain (TEG) measured using commercially available barometric altimeters, in dry weather condition.

	SRM PC7	Garmin Edge
Climb A (TEG 160 m)	1.5	1.2
	(1.3, 1.8)	(1.1, 1.4)
Climb B (TEG 245 m)	0.9	1.1
	(0.7, 1.3)	(0.9, 1.4)
Climb C (TEG 1045 m)	1.4	1.5
	(1.1, 1.9)	(1.2-2.2)
Overall	1.5	1.9
	(1.3, 1.8)	(1.7-2.1)

Table 2. Percentage bias (with 90% confidence interval) of Total Elevation Gain (TEG) measured by commercially available devices compared to the criterion TEG, in dry weather conditions.

	SRM PC7	Garmin Edge
Climb A (TEG 160 m)	-5.4	-1.3
	(-5.0, -5.8)	(-1.0, -1.5)
Climb B (TEG 245 m)	-5.6	-4.6
	(-5.3, 6.0)	(-4.3, -5.0)
Climb C (TEG 1045 m)	-4.0	-3.0
	(-3.4, -4.5)	(-2.4, -3.7)
Overall	-5.1	-2.3
	(-4.9, 5.4)	(-1.9, -2.7)

should further investigate the accuracy of commercially available devices to determine their validity over longer activities involving subsequent uphill and downhill sections and in different weather conditions.

In conclusion, the results of the present study indicate that measurements of total elevation gain were accurately measured by barometric altimeters; however, weather conditions, in particular in rain and low barometric pressure, could potentially negatively influence the accuracy.

Practical applications

This study results are useful to researchers aiming at describing the physiological demands of competitions, allowing them to rely on accurate elevation gain data in their research. Furthermore, this study results promote the use of accurate elevation data when modelling road cycling performances. Furthermore, riders and coaches monitoring training load should only rely on accurate measures of elevation gain. Finally, this study results highlight the limitations of barometric altimeters in specific weather conditions raising awareness on potential measurement errors.

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Conflict of interest

No financial assistance was provided for this project. The results of the current study do not constitute endorsement of the product by the authors or the journalstudy.

References

1. Cummins C, Orr R, O'Connor H, West C (2013) Global positioning systems (GPS) and microtechnology sensors in team sports: a systematic review. Sports Med 43: 1025-1042
2. de Magalhaes FA, Vannozzi G, Gatta G, Fantozzi S (2015) Wearable inertial sensors in swimming motion analysis: a systematic review. J Sports Sci 33: 732-745
3. di Prampero PE, Cortili G, Mognoni P, Saibene F (1979) Equation of motion of a cyclist. J Appl Physiol Respir Environ Exerc Physiol 47: 201-206
4. Gardner AS, Stephens S, Martin DT, Lawton E, Lee H, Jenkins D (2004) Accuracy of SRM and power tap power monitoring systems for bicycling. Med Sci Sports Exerc 36: 1252-1258
5. Hannas BJ, Goff JE (2005) Inclined-plane model of the 2004 Tour de France. Eur J Phys 26: 251-259
6. Harriss DJ, Atkinson G (2011) Update--Ethical standards in sport and exercise science research. Int J Sports Med 32: 819-821
7. Lee J, Finkelstein J (2014) Activity trackers: a critical review. Stud Health Technol Inform 205: 558-562
8. Menaspà P, Impellizzeri FM, Haakonssen EC, Martin DT, Abbiss CR (2014) Consistency of commercial devices for measuring elevation gain. Int J Sports Physiol Perform 9: 884-886
9. Perrin O, Terrier P, Ladetto Q, Merminod B, Schutz Y (2000) Improvement of walking speed prediction by accelerometry and altimetry, validated by satellite positioning. Med Biol Eng Comput 38: 164-168
10. Petersen C, Pyne D, Portus M, Dawson B (2009) Validity and reliability of GPS units to monitor cricket-specific movement patterns. Int J Sports Physiol Perform 4: 381-393
11. Pyne D (2008) Measurement studies in sports science research. Int J Sports Physiol Perform 3: 409-410
12. Scarf P (2007) Route choice in mountain navigation, Naismith's rule, and the equivalence of distance and climb. J Sports Sci 25: 719-726
13. Scarf P, Grehan P (2005) An empirical basis for route choice in cycling. J Sports Sci 23: 919-925