Original Article

Validity and reliability of STRAVA segments: Influence of running distance and velocity

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ABSTRACT

This study aimed to assess the reliability of Strava measurements when manipulating segment distance and running velocity. The tests were carried out on a flat and straight segment. Ten male regular runners were equipped with a Garmin® Forerunner 945 watch and ran over a distance of 1 km of four increasing speeds: 1.39, 2.78, 4.17 and 5 m/s. Different reference positions were accurately determined in order to calculate time at 100 m, 200 m, 500 m, 700 m, and 1000 m. A bike with a wide angle camera was used to standardize the run pace and to record the entire run for reference measurements. Results show a high level of reliability with nearly perfect intra-class correlation (from .997 to 1) when data is analysed accordingly to the distance of the segment or to the running velocity. The validity is also very good with a small average bias (-0.25 s), a standard deviation of differences of 1.84 sec and the limit of agreement range from -3.86 to 3.35 sec. Regardless of the length of the segment, the actual performance of the runner is normally within +/- 2 seconds of the results given by the Strava application. In 95% of cases, the measurement error will be less than four seconds. The relative error is proportionally larger for short segments done at a fast pace. Further studies are needed to explore Strava segments reliability in other specific contexts.
Keywords: Performance analysis of sport, Accuracy, GPS technology, Running watch, Endurance running.

Cite this article as:
De Cock, F., Dardenne, N., Jockin, F., & Jidovtseff, B. (2023). Validity and reliability of STRAVA segments: Influence of running distance and velocity. *Journal of Human Sport and Exercise, in press*. https://doi.org/10.14198/jhse.2023.184.05

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Submitted for publication February 17, 2023.
Accepted for publication March 13, 2023.
Published *in press* April 28, 2023.
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi:10.14198/jhse.2023.184.05

INTRODUCTION

Wearable devices including Global Navigation Satellite Systems such as GPS technology are widely used by runners in order to monitor their training and competitions (Moore & Willy, 2019; Nielsen et al., 2013; Powell et al., 2014). According to Wiesner et al. (Wiesner et al., 2018), the most frequent parameters of interest are the distance covered, time and average speed. As GPS data are widely used to monitor and regulate training activities, it's important to know if they are valid and reliable (Cunniffe et al., 2009; Nielsen et al., 2013; Pobiruchin et al., 2017). Studies show that the validity and reliability of GPS systems depend on the activity analysed, the characteristics of the equipment and the environment in which the recordings were made (Malone et al., 2017; Ranacher et al., 2016). The number of available satellites as well as their geometric distribution in the sky influence the quality of data (Malone et al., 2017). Environmental factors such as vegetation density, cloud coverage, geographic relief, size and proximity of buildings, and width of the streets are known to affect GPS accuracy (Gilgen-Ammann et al., 2020; Nielsen et al., 2013; Rainham et al., 2008; Schipperijn et al., 2014; Vorlíček et al., 2021). Currently, GPS units can be configured at very different sampling rate, according to activity pattern and the duration of the recording (Yang & Hsu, 2010). In the context of endurance running, a sampling frequency of 1Hz is mostly recommended (Schutz & Herren, 2000; Townshend et al., 2008). The validity of GPS distance appears to be affected by path linearity and movement intensity. Measurements from GPS signal were reported to be more accurate in straight line segments when compared to curved segments (Gray et al., 2010; Nielsen et al., 2013). Recent work by Johansson et al. (Johansson et al., 2020) has shown that the distance measured by a GPS watch on a segment with curves is lower than the actual distance.

Most GPS running devices are compatible with software and/or application designed to transfer raw data to a platform that provides some automated processing and a visual display of the activity. With over 100 million athletes in 195 countries in 2022, Strava has become the most popular platform including website and mobile app dedicated to tracking physical activity and to offer training support (Strava, 2022a; West, 2015). It is widely use in the runner's community who openly shares GPS recorded workouts. Strava popularity increased particularly during the COVID-19 pandemic as it offers, especially during lockdown periods, opportunities for people to be followed up, to participate in virtual challenges or competitions and to be connected to friends and peers' trough virtual community while social distancing and restrictions prevent group training and events (Couture, 2021; Fischer et al., 2022). One of the most innovating features of Strava is the concept of segments, which are portions of road or trail created by members where athletes can compare times. The introduction of segments concept makes it possible to measure and compare the performance of athletes when running at the same place but at different times. The recording of Strava members activities are registered into a big database, allowing the platform to build historic classification of all runners that have passed through a segment. Performance of the athletes are recorded for every run allowing comparisons and follow-up. This new approach, enabled by technological advances, is likely to transform training practices and the monitoring of athletes. Trophies, challenges, performance visualizations and "*Kudos*" (which are the Strava equivalent of a "*Like*" on other social platforms) are game elements that trigger motivational mechanisms and contribute to the success of Strava (Creany, 2020). Strava gives athletes simple, fun ways to stay motivated and to compete against themselves and others without having to be in the same place at the same time (Meireles & Ribeiro, 2020; Shei, 2018; West, 2015). While time measurement obtained from Strava segments are becoming increasingly useful in running athletes' follow-up and comparisons, we don't have scientific data on their validity and reliability.

This study addresses the fundamental need to verify the quality of this data offered by the Strava application. At this time and to the authors' knowledge, no scientific study has yet addressed this issue. The purpose of this study is, in a simple and very standardized context, to assess the validity and reliability of Strava measurements when manipulating two variables: segment distance and running speed. Additionally, the research aims to determine in a very standardized situation the error in measurement associated with time measurement during Strava segment running.

METHODS

Experimental approach to the problem

To investigate the validity and reliability of Strava segments, it was necessary to compare the timings given by the application with those actually measured in the field. In order to standardize the experimental conditions as much as possible, five Strava segments from 100 to 1000 m in length were created in an open environment and on a straight line. Landmarks corresponding to the start and end of the Strava segments were precisely marked along the course. The procedure was replicated at 4 increasing speeds. The runners pace was regulated by a cyclist. A wide angle camera, mounted on the bike, was used to accurately measure time on each segment and in each speed condition.

Subjects

Ten male regular runners, aged between 18 and 32 years volunteered to participate in the study. The inclusion criteria were to be uninjured at the time of testing and to be able to run at the speed of 20 km/h for at least one kilometre. A written informed consent with explanations of all procedures was obtained from all participants. This study was conforming to the Declaration of Helsinki and was approved by the ethical committee of the University of Liege.

Procedure

All participants were equipped with a Garmin® Forerunner 945 watch (Garmin Ltd., Olathe, USA) in order to record each run. The watch was configured in "*running mode*" and received Global Navigation Satellite Systems from GPS and Glonass systems at the sampling frequency of 1 Hz. Before starting the recording, the participants were told to remain still while the watch searched for satellites. This procedure can take from 30 to 60 seconds and is validated when each GPS system is locked on to the signal of at least 3 satellites.

The tests were carried out on a flat and straight segment in an uncovered area. The subjects had to run over a distance of 1 km at four increasing speeds: 1.39, 2.78, 4.17 and 5 m/s (respectively 5, 10, 15 and 18 km/h). Different reference positions were accurately determined with an odometer in order to standardize the procedure and calculate the intermediate crossing times at 100 m, 200 m, 500 m, 700 m, and 1000 m. Lines were drawn on the ground and signs were placed at each reference point. Exact position of the starting line and of each intermediate position were identified on the field according to physical landmarks that are also identifiable from the Strava application through Google Earth. Starting and ending position corresponding the landmarks were virtually located on the Strava application in order to build five virtual Strava segments. Particular attention was focused on ensuring that each virtual segment corresponded to its positioning and in distance to the real segments determined on the track. Each Strava segments was created from a preliminary recording.

In order to determine real timing data and standardize the race pace, a wide angle wearable camera (GoPro HD Hero 4, San Mateo, USA) was placed on a bike. The researcher ensured that the bike was driven at the constant speed determined by the protocol and stood next to the runner at a regular distance so that the camera recording could easily identify the precise moments when the runner passed the landmarks corresponding to the Strava segments. The camera was set at a resolution of 1920 x 1080 pixels and recorded at 30 frames per second. Timing for each segment was determined by subtracting the time recorded when the subjects pelvis reached the line of a segment from the time recorded when the subjects pelvis reached the starting line. The results were considered as reference (REF) data. In order to ensure a constant velocity since the beginning of the segment and to guarantee Strava segment identification recording, the subject and the researcher started 10 meters before the starting line and stopped effort 10 meters after the finish line.

To use a Garmin® watch on the Strava application, both a specific Strava and a Garmin Connect account were created for the research. The synchronization and sharing of data between the two applications was automatically done. Strava measurements (STRAVA) were automatically calculated for each created segment on the application. Time for each Strava segment was individually extracted and encoded in an Excel file with a 1 second precision.

Statistical analysis

Statistical analysis was performed with Statistica software (Version 13.2, TIBCO Software Inc, USA). A two-way mixed absolute agreement intra-class correlation coefficient (ICC) was used to investigate the reliability between STRAVA and REF measurements. Bland-Altman plot method including the mean of differences (MD = systematic bias) with 95% confident interval (CI95%), standard deviation of differences (SDD), standard error of differences (SED) and limits of agreement (LA = MD ± 1.96SDD) were used to investigate degree of agreement between STRAVA and REF measurements. Relative difference (RD) was calculated as the standard deviation of ratios between difference in time and time of REF measurements. The normality was investigated graphically and through the Kolmogorov Smirnov test. The normality hypothesis appeared to be respected, allowing the use of parametric tests. A repeated measure analysis of variance (ANOVA) was used to test the effect of velocity and segment length on residuals between STRAVA and REF. Tukey HSD test was used for post-hoc comparisons. Statistical significance was set at $p < .05$ level.

RESULTS

Table 1 provides descriptive statistics for REF and STRAVA time measurements in each velocity and segment condition. SDD ranged from 0.4s in the longest segment covered at the highest speed to 3.1s in the longest segment covered at the slowest speed. RD systematically decrease with segment length and was the highest (4.2%) in the 100m segment at 5m/s. Table 2 presents analysis of reliability (ICC), bias, standard deviation of the difference (SDD), standard error of the difference (SED) and limits of agreement (LA) of STRAVA segment time in comparison with REF values according to segment distance (100 m, 200 m , 500 m, 700 m and 1000 m) and velocity (5, 10, 15 and 18 km/h).

The reliability is almost perfect with ICC ranging from .997 to 1 according to the velocity and the distance. Systematical bias was -0.25 sec on average. Standard error of differences between STRAVA and REF reached 1.84 sec on average and ranged between 0.74 and 2.38 sec according to the context. The 95% agreement interval was limited from -3.86 to 3.35 sec when considering all measurements. Among our observations, 92% of STRAVA measurements were under 5% of error. The Bland-Altman plot (Figure 1) illustrates the amplitude of the difference between STRAVA and REF measurement for all recordings according to velocity.

The repeated measure ANOVA revealed that there was no distance effect (F = 1.48 ; $p = .23$) but a velocity effect (F = 17.74 ; $p < .001$) on the differences in time measurements between STRAVA and REF. Post-Hoc analysis revealed there were no significant measurement bias within each segment distance. However, significant differences ($p < .001$) between STRAVA and REF were observed for each specific velocity. Strava time measurement was superior at 5km/h, while it was lower at 10, 15 and 18 km/h. MD was significantly different at 5km/h in comparison with all other velocities ($p < .001$) while there was no difference in MD between 10, 15 and 18km/h.

Table 1. Average (±standard deviation) time for REF and STRAVA measurement, according to velocity and segment distance. Standard deviation of the difference (SDD) and relative difference (RD) between REF and STRAVA.

Velocity	Segment (m)	REF (s)	STRAVA (s)	SDD (s)	RD (%)
	100	68.9 ± 1.7	70.2 ± 2.7	2.2	3.2%
	200	141.4 ± 2	142.6 ± 2.9	2.7	1.9%
1.39m/s (5km/H)	500	354.7 ± 6.6	357.4 ± 6.7	2	0.6%
	700	498.1 ± 8.4	499.1 ± 8.4	1.7	0.3%
	1000	715.2 ± 10.1	716.1 ± 9.1	3.1	0.4%
	100	36.3 ± 0.4	35.1 ± 1.4	1.4	3.9%
	200	73.4 ± 0.4	72.1 ± 1.4	1.2	1.6%
2.78m/s (10km/H)	500	179.4 ± 1.5	178 ± 1.8	1.5	0.8%
	700	249.4 ± 2.8	249.4 ± 2.8	1.3	0.5%
	1000	355.4 ± 5.5	354.9 ± 5.3	0.8	0.2%
	100	23.9 ± 0.8	23.8 ± 1.4	0.9	3.9%
	200	48.5 ± 1	47.2 ± 1.7	1.1	2.3%
4.17m/s (15km/H)	500	120.4 ± 2.7	120.4 ± 2.3	1.6	1.3%
	700	168.9 ± 3.2	167.3 ± 3.2	1.4	0.8%
	1000	240 ± 3.7	238.9 ± 4.6	1.3	0.5%
	100	19.5 ± 0.9	18.7 ± 1.3	0.8	4.2%
	200	40 ± 1.1	39.1 ± 1.4	0.7	1.9%
5m/s (18km/H)	500	99.8 ± 0.4	98.9 ± 1	0.9	0.9%
	700	140 ± 0.7	139.6 ± 1	0.8	0.6%
	1000	200.6 ± 1.9	199.9 ± 1.9	0.4	0.2%

Table 2. Analysis of reliability (ICC), bias, standard error of measurement (SEM), standard error of the difference (SE) and limits of agreement of STRAVA segment time in comparison with REF values according to segment distance and velocity.

		ICC	MD (CI 95%) (s)	SDD (s)	SED(s)	LA (s)
Distance (m)	100	0.997	-0.19 [-0.72 ; 0.35]	1.67	0.26	[-3.47 ; 3.09]
	200	0.999	-0.57 [-1.17 ; 0.04]	1.88	0.30	[-4.26 ; 3.13]
	500	1.000	0.1 [-0.61 ; 0.81]	2.21	0.35	[-4.22 ; 4.42]
	700	1.000	-0.26 [-0.77 ; 0.24]	1.58	0.25	[-3.37 ; 2.84]
	1000	1.000	-0.36 [-0.94 ; 0.22]	1.82	0.29	[-3.92 ; 3.21]
Velocity ($m.s^{-1}$)	1.39	1.000	1.42 [0.74 ; 2.1]*#	2.38	0.34	[-3.25 ; 6.09]
	2.78	1.000	-0.89 [-1.26 ; -0.51]*	1.33	0.19	[-3.49 ; 1.72]
	4.17	1.000	-0.81 [-1.21 ; -0.42]*	1.39	0.20	[-3.54 ; 1.92]
	5	1.000	-0.74 [-0.95 ; -0.53]*	0.74	0.10	[-2.18 ; 0.7]
Average		1.000	-0.25 [-0.51 ; 0]	1.84	0.13	[-3.86 ; 3.35]

*Note. * Significant difference between STRAVA and REF measurements ($p < .001$). # Significant difference in MD between 1.39 and other velocities ($p < .001$).*

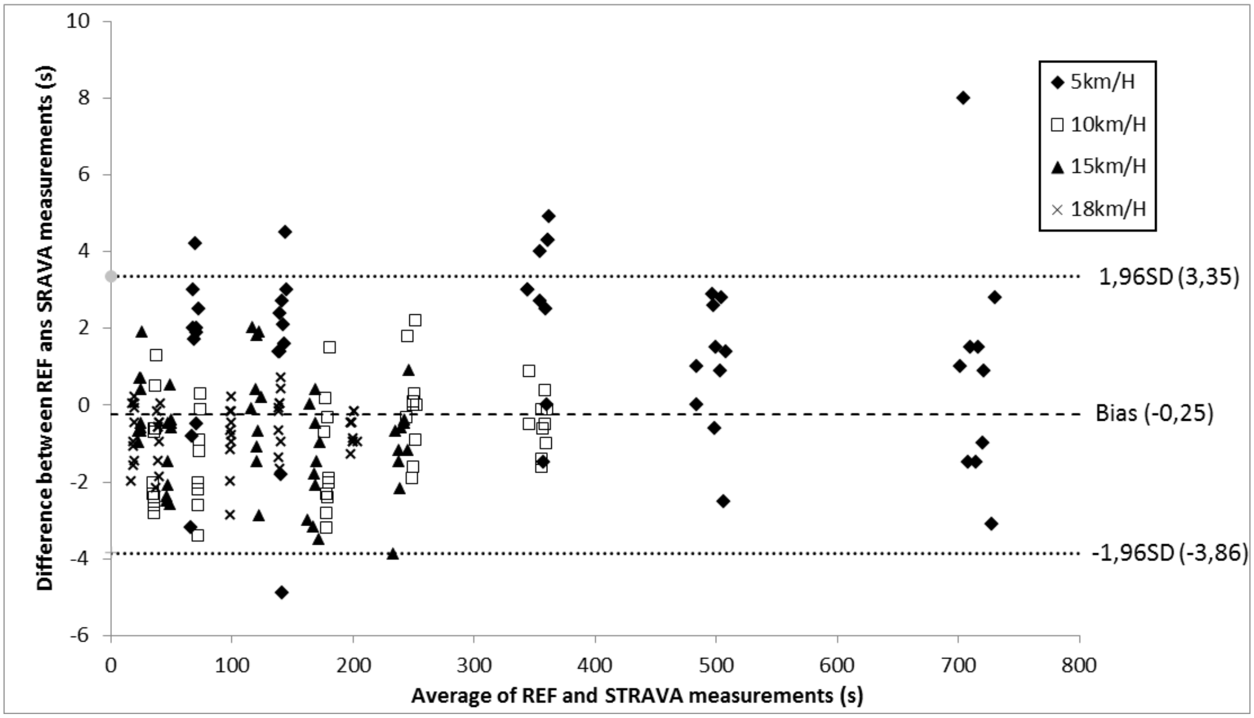

Figure 1. Bland-Altman Plot comparing STRAVA with REF in each velocity condition. Bias and limits of agreements are averaged from all conditions measurements.

DISCUSSION AND CONCLUSIONS

To our knowledge, this is the first study that investigates the reliability and validity of time measurements from Strava segments. Timed segments is a new concept and most of the research on the use of GPS in running has investigated the reliability of distances covered or running velocity (Gilgen-Ammann et al., 2020; Johansson et al., 2020; Lluch et al., 2021; Schutz & Herren, 2000; Townshend et al., 2008) making comparisons difficult. On the basis of indirect comparisons that can be made, our results show high level of reliability with nearly perfect ICC (from .997 to 1) when data is analysed accordingly to the distance of the segment or to the running velocity. Distance-based studies also show correlation coefficients close to 1 (Townshend et al., 2008) and relative errors below 2% (Adamakis, 2017; Dumas, 2022; Johansson et al., 2020; Nielsen et al., 2013). The validity is also very good with a small average bias (-0.25 s), a SDD of 1.84 sec and the limit of agreement range from -3.86 to 3.35 sec. This suggests that on average, we can expect from Strava segments to have a time error of less than two seconds and that an error of over four seconds is rare.

An important result of our study is that the length of the segment does not have a significant effect on the time measurement error. Some researchers (Scott et al., 2015) have underlined a lower reliability for very short distance (between 10 and 40m) which cannot be used for STRAVA segments. In fact, the error related to the GPS positioning in any segment time measurement remains the same whether the finish line is 100 or 1000 m from the start line. Systematical bias observed for each segment distance remain low and not significant. Minor variation in time measurement is mainly due to two sources of error. The first one is related to the GPS positioning of the runner and has been previously described to be under 5m in an open environment (Lluch et al., 2021; Vorlíček et al., 2021). Our study is in accordance with these results as when we multiply the time error observed for each measurement by running velocity we obtain on average an error of 4.0 ± 3.2 meters. The second source of error comes from the distance of the STRAVA virtual segment which has a beginning and an end that cannot be determined as accurately as on the field. STRAVA segment exact length depends on the platform algorithm whose level of accuracy remain unknown and consequently may lead to small errors.

One major result of the present study is that error in time measurement decrease when velocity increase. Such velocity effect are not in accordance with some previous studies which have highlighted an increase in GPS error with an increase in running velocity (Jennings et al., 2010; Johnston et al., 2012). However, these studies were conducted in very different contexts of exercise, including team sport, which require various displacements of short in line running and change of direction. The research of Adamakis et al. (Adamakis, 2017) revealed no significant differences between walking and running velocities while the research of Lluch et al. (Lluch et al., 2021) supported our results by showing that the slower the pace is, the greater the error. These inconsistent results confirm that the context of measurement and exercises is of great importance and has to be considered before any comparison. Interestingly STRAVA algorithm tends to overestimate time measurement at the slowest speeds which correspond to walking while a small but significant underestimation has been observed in all running velocities (i.e. from 10 to 18 km/h). At walking speed (1.39 m/s), the short distance between two recorded positions involves that it takes longer to get out of what STRAVA application can consider to be the "*error zone*". The increase in speed seems to allow a higher level of accuracy in the STRAVA algorithm since we observe the lowest absolute difference (SDD) at the highest running speed. At high speeds, the segments are covered more quickly. An absolute error of 2 seconds, for example, will have a greater relative impact than at low speeds. Our results show that while the absolute error of measurement is indeed much higher in the long segments run at low speed (SDD = 3.1s in 1000m segment at 1.39 m/s), the relative error is highest for the 100 segment run at 5 m/s (RD = 4.2%). This shows that a short segment is a problem for validity and our results show that for a relative error of about 2%, the segments should be at least 200m long. Further studies are needed to better understand the relationship between speed and reliability of GPS data.

This study is the first to investigate with a rigorous protocol the validity and reliability of Strava segments and that offers an estimate of the error measurements. Our results are applicable in contexts which are similar to those described in this study and consequently have limits. Most STRAVA segments are not in lines and include change of altitude, curves and turns as well as forest covered areas which are known to alter distance measurements (Gilgen-Ammann et al., 2020; Nielsen et al., 2013; Rainham et al., 2008). It is plausible that most Strava segments which are easily identifiable at their beginning and end would meet the same level of reliability for time measurement. As many contexts haven't been investigated in the present study, more research is still needed to fully understand how Strava segment performance can be influenced by the technological tools used, by the environment in which exercise is performed, by the type of itinerary and by the effort itself. Additionally, we have to be aware that performance in Strava segment depends not only on the raw data recorded by the watch but also on platform algorithms which are specific to the Strava Software (Strava, 2022b) and may influence the results. Another limitation is the small size of our sample. This number appeared to be sufficient in the context of this highly standardized study and offers valuable indications for the level of validity of STRAVA segments in similar conditions, but studies on larger samples and under all specific running conditions seem necessary to fully understand the limits of validity of STRAVA segments and to define recommendations for their use.

Practical applications

This study has shown that time measurements obtained from Strava segments have an excellent validity when running is achieved in a straight line in an open environment. The data obtained from this study provides a useful benchmark that can be used by athletes and coaches to interpret the performance obtained from the Strava application with the necessary precaution. Regardless of the length of the segment, the actual performance of the runner is normally within +/- 2 seconds of the results given by the Strava application. In more than 95% of the cases, the measurement error will be less than four seconds. While absolute error appears to the highest for long segment done at slow pace, relative error is the highest for short segments done at fast pace. Whatever the running speed, the length of a segment should be at least 200m to guarantee an error of about 2%.

AUTHOR CONTRIBUTIONS

Study conception and design: F. De Cock, B. Jidovtseff; data collection: F. Jockin, F. De Cock, B. Jidovtseff; analysis and interpretation of results: N. Dardenne, F. De Cock, B. Jidovtseff, F. Jockin; draft manuscript preparation: F. De Cock, B. Jidovtseff; writing—review and editing: De Cock, B. Jidovtseff, N. Dardenne.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

ACKNOWLEDGMENTS

The authors wish to thank all the runners for participating in this study.

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