Sports Biomechanics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rspb20

Validation of a global positioning system with accelerometer for canoe/kayak sprint kinematic analysis

Rui António Fernandes, Fernando Alacid, André Branquinho Gomes & Beatriz Branquinho Gomes

To cite this article: Rui António Fernandes, Fernando Alacid, André Branquinho Gomes & Beatriz Branquinho Gomes (23 Nov 2021): Validation of a global positioning system with accelerometer for canoe/kayak sprint kinematic analysis, Sports Biomechanics, DOI: 10.1080/14763141.2021.2005128

To link to this article: https://doi.org/10.1080/14763141.2021.2005128

Published online: 23 Nov 2021.

SPORTS BIOMECHANICS
https://doi.org/10.1080/14763141.2021.2005128

Validation of a global positioning system with accelerometer for canoe/kayak sprint kinematic analysis

Rui António Fernandes [a], Fernando Alacid [b], André Branquinho Gomes [c] and Beatriz Branquinho Gomes [a]

[a]Research Unit in Sport and Physical Activity, Faculty of Sport Sciences and Physical Education, University of Coimbra, Coimbra, Portugal; [b]Department of Education, Health Research Centre, University of Almeria, Almeria, Spain; [c]Research Unit in Sport and Physical Activity, University of Coimbra, Coimbra, Portugal

ABSTRACT

This study aimed to validate the use of a Global Positioning System with an accelerometer (GPS-Acc) unit to quantify canoeing kinematic variables. Eight canoe and kayak (200 and 500 m) sprint races were analysed. All the races were recorded sideways by a digital camera that followed the kayak or canoe bow and simultaneously using a GPS-Acc unit recorded the data concerning boat position, velocity, and acceleration. In 200 m races, 50 m splits were established over the entire race distance. In 500 m races, 100 m splits were used, excepting the race start and end, where the splits were divided into two sections of 50 m. The data of the GPS-Acc unit were analysed using a self-developed routine. The agreement between the video and the GPS-Acc analysis was measured regarding all the variables by a Bland-Altman analysis. No differences were found between both methodologies, except for time and velocity at the first 50 m, suggesting thus an agreement between the analysis methods. The GPS-Acc unit is valid for measuring quickly and accurately kinematic variables, mainly boat velocity and stroke rate. However, video analyses may be necessary when a more detailed analysis of the paddling technique is of interest.

ARTICLE HISTORY
Received 23 January 2021
Accepted 6 November 2021

KEYWORDS
Canoe sprint; validation; kinematic; analysis

Introduction

Canoe Sprint is one of the most popular competitive canoeing discipline. Kayak and canoe competitions are held over distances of 200 m, 500 m, and 1000 m in boats that can be crewed by one, two, or four athletes. Most athlete's training evaluation is conducted in laboratory environment (Fleming et al., 2012; Gomes et al., 2012; Harrison et al., 2019; Limonta et al., 2010) and few studies in controlled training situations on the water (Bonaiuto et al., 2020; Gomes et al., 2015, 2020; McDonnell et al., 2012). These assessments are often used to measure performance or evaluate training effects, but there is a disadvantage in laboratory tests of ergometers because they do not fully replicate the sport's specific performance (Larsson, 2003).

CONTACT Rui António Fernandes rui.fernandes@uc.pt
This article has been republished with minor changes. These changes do not impact the academic content of the article.

In canoeing, video analysis (VID) is a standard tool for kinematic analysis (Alacid et al., 2005; Vaquero-Cristóbal et al., 2013), since the paddler and kayak/canoe are recorded sideways from a motorboat or vehicle following the race/training situation. Using the buoys on the course as distance references (Sperlich & Baker, 2002), variables such as boat velocity (V), stroke rate (SR), stroke length (SL), and split times (ST) could be calculated. In addition, considering that the SR usually establishes training intensity in canoeing, the coaches often quantified it by using stopwatches. Different studies carried out on canoeing suggested that the SR is the variable that best correlates with performance (Brown et al., 2011; Gomes et al., 2015, 2020; McDonnell et al., 2013). Nowadays, it is possible to measure the SR by using a sensor attached to the paddle shaft and synchronised with a sportwatch or smartphone. However, it increases the paddle weight, which could interfere with the technique, aside from the fact that its use is not allowed in competition.

Global positioning system (GPS) technology has rapidly advanced over the last few tears. It has become a standard method for assessing the physical demands of training and competition in field based sports (Aughey, 2011). For example, studies conducted in swimming accurately enabled the stroke count detection for all four-stroke styles using the GPS technology (Le Sage et al., 2011; Siirtola et al., 2011; Thomas et al., 2010). GPS devices facilitate a more objective planning, by attempting to optimise future performances (Scott et al., 2016). These devices have been replacing the time-consuming and laborious VID methods to quantify the athlete's kinematics in many team sports (Coutts & Duffield, 2010). Moreover, the significant advantage of using these devices is that they enable to monitor athletes in real performance situations.

The International Canoe Federation allows units without real-time information in competition (World Cups, World Championships, and Olympic Games). Since 2017, it has been using GPS/Accelerometer (GPS-Acc) units containing a 10 Hz GPS (ST Innovation, Geneva, Switzerland). Goreham et al. (2020) used these data in their study to investigate the pacing strategies of elite athletes and analysed the differences between medallists and non-medallists. Furthermore, some studies used GPS-Acc technology to analyse kayaking performance in a training environment (Bifaretti et al., 2016), and even to analyse the SR, comparing data from the GPS-Acc unit with the video analysis (VID) (McDonnell et al., 2012). Bifaretti et al. (2016) suggested that a high refresh frequency of the GPS module (10 Hz) could evaluate the intra-cyclic velocity variation, which may not be possible with a standard 1 Hz device, since it depends mainly on the SR values. On the other hand, McDonnell et al. (2012), when testing sprint kayakers performance, compared the SR values calculated based on GPS-Acc data (1 Hz GPS and 125 Hz Acc) to the video information (60 Hz; a camera mounted on the deck of the kayak) and found that GPS-Acc was not a valid measure for the SR. Therefore, they suggested the use of VID (McDonnell et al., 2012). Probably this result was due to the low GPS sampling rate used by these authors.

Although GPS-Acc units' frame rates have increased over the past years, their data have not been validated in comparison with the VID. Therefore, investigation in this field of research is still scarce. Thus, this study aimed to assess and validate the use of GPS-Acc technology to quantify canoeing kinematic variables. The agreement between VID and GPS data for boat velocity was hypothesised as well as the possibility of obtaining accurate SR measurements with Acc data, in contrast to the ones performed using the VID.

Materials and methods

Participants and data collection

Data were collected in 2018 during the Portuguese Canoe Sprint National Championships and the International Canoe Federation Canoe Sprint World Championships. Both events were held at the High-Performance Center of Montemor-o-Velho, Portugal.

Eight races were considered for analysis in the present study, corresponding to the K1 200 m junior men (Heat and A Final) and women (Heat, Semi-final, and A Final), the K4 500 m senior men (Heat), the K2 500 m junior women (A Final) and C1 500 m senior men (Heat). With their agreement, all athletes were filmed during the race, and their boats had a GPS-Acc unit. This study received approval from the ethics committee (CE/FCDEF-UC/00322018).

Following the instructions of the official international canoeing competitions, the race started with the athletes aligned on the respective lanes with an automatic start system (Tegysport S.A.S; Macerata, Italy). At the start of the race, all boats had their bow on the starting bucket. And the starting frame considered was the one in which the bucket started to drop. The athletes' reaction time was not assessed.

In 200 m races, 50 m splits were established over the entire race distance. Meanwhile, 100 m splits were used in 500 m races, except for the first and last sections, which were divided into two sections of 50 m. The 0–50 m and 450–500 m splits were analysed because the error tends to be greater in these smaller splits than in the larger ones (Alacid et al., 2005). The variables assessed were the race time (ART), the average stroke rate (ASR), and the velocity (AV). For the first 50 m split, time (TF50), stroke rate (SRF50), and velocity (VF50) were assessed. For the last 50 m split, time (TL50), stroke rate (SRL50), and velocity (VL50) were assessed; and for each intermediate 100 m splits, time (T100), stroke rate (SR100), and velocity (V100) were assessed.

The video recording was carried out by means of a digital camera with a recording mode at 30 frames per second (fps), mounted on a camera stabiliser (Xiaomi Mijia Gimbal Model SJYT01FM, Beijing, China). The entire race was recorded sideways accompanying the athlete, always following the kayak or canoe bow when passing the marking buoys (that were placed every 10 m on each lane of the course) and adjusting whenever necessary to facilitate the data analysis. The resulting recordings were analysed by using the software *Kinovea—0.8.15*. The data obtained from the digitalisation were registered in a Microsoft© Excel spreadsheet (Microsoft Corporation, USA). In order to calculate velocity, the frame, in which the boat's bow was aligned with the two buoys that marked each split, was determined (Figure 1).

Subsequently, the distance analysed was divided by the number of frames elapsed in the split by 30 fps (frames per second), obtaining results in m.s^{-1}. In order to determine the SR, the methodology described by Alacid et al. (2005) was used. Thus, the complete stroke cycles were counted for each split, considering the frame in which the paddle blade on the recording side came into contact with the water. These frames were always equal or superior to those used to determine the velocity, that is, the first blade entry was

Figure 1. Example of the video analysis frame to consider bow alignment with the two buoys that mark a split.

performed after completing the split. All athletes started their race with the left paddle submerged, and the race was filmed from the right side. An additional stroke was added for the first 50 m.

After getting these data, the number of stroke cycles obtained in the elapsed frames was divided by 30 fps, and the results were expressed in cycles.s^{-1} (Alacid et al., 2005). Since the stroke rate is commonly used in canoeing and displayed as the number of strokes per minute (spm) (McDonnell et al., 2013), the previous number was multiplied by 60 seconds. Finally, two experienced observers that are experts in canoeing (one of them has a published study using the aforementioned methodology) analysed the video data.

Simultaneously, the boat displacement, velocity, and acceleration were obtained by using a wireless unit with a 15 Hz GPS and a 3D IMU. This unit contains 12 channel receivers that track up to 12 satellites at any time. It is combined with a triaxial accelerometer with a sampling rate of 100 Hz (GPSPORT, Canberra, Australia) and it is fixed on the stern of the deck of the kayak/canoe, synchronising GPS and IMU data. The data were extracted to spreadsheets with the software Team AMS R1 2016.7. Then, they were exported to Matlab® R2019b (The MathWorks Inc., Natick, MA) and analysed using a routine especially developed for this application. In the routine, the investigator had to identify the start of the race by taking into consideration the first index in which the velocity changed from 0 m.s^{-1} to a higher value (representing the start of the race). Afterwards, taking into account the data position (x and y coordinates), the routine itself identified the end of the race, evaluating the total distance (200 or 500 m) and the different splits in analysis. At the same time, by considering the defined splits, the velocity was computed for the total race distance and splits (50 and 100 m). Furthermore, the SR was added (total race and splits) by considering kayak longitudinal acceleration. A fourth-order low-pass Butterworth filter with a cut-off frequency of 10 Hz was used to smooth the acceleration data (Winter, 2009) and to identify each stroke by a single peak. The displacement splits data (50 or 100 m) enabled to determine the acceleration data cuts and identify the total strokes per distance split. The variables analysed were the average velocity (race and splits), the average stroke rate (race and splits), and the total race time.

Statistical analysis

The normality and homogeneity of the variance hypotheses were verified using the Shapiro-Wilk and Levene's tests. Spearman's correlation coefficients (*rs*) were calculated to examine the correlation between the outcomes. These coefficients were considered as a very high correlation when the value is between 0.9 and 1, a high correlation when between 0.7 and 0.9, a moderate correlation when between 0.5 and 0.7, a low correlation when between 0.3 and 0.5, and a negligible correlation when between 0 and 0.3 (Mukaka, 2012).

The difference between the methods concerning the mean values was analysed using the one-sample t-test. In addition, a one-way analysis of variance (ANOVA) was used to examine the differences between the race time resulting from the VID, the race time resulting from the GPS-ACC, and the race official time.

The level of significance was set at $p < 0.05$. Cohen's d was used to measure the effect size of the observed differences and was considered small when the value was between 0.2 and 0.5, moderate when between 0.5 and 0.8, and large when the effect was > 0.8 (Cohen, 1988).

The agreement between methods was explored concerning all the variables, systematic bias and random error calculated by Bland-Altman analysis (Bland & Altman, 1990; Bland & Altman, 1986), including upper and lower limits of the agreement (LOA) through the typical error $\left(\frac{SD}{\sqrt{2}}\right)$ as suggested by Hopkins (2000). Consequently, the 95% LOA was calculated by $\left(\pm\left(1.96s.\sqrt{2}\right).\left(\sqrt{2}\right)s\right)$ The coefficient of variation (CV%) was calculated as $\left(\frac{s}{mean}.100\right)$, LOA 95% confidence intervals were calculated in Microsoft® Office Excel 365. Furthermore, the heteroscedasticity was examined using linear regression, inserting the difference from the mean values between methods as the dependent variable, and the average values [(value for VID + value for GPS-ACC)/2] as the independent variable (p < 0.05). The statistical analyses were performed using SPSS Statistics 24.0 (SPSS Inc., Chicago, IL).

Results

The kinematic variable's results are summarised regarding both methods, the VID analysis and GPS-Acc unit, in Table 2. They were normally distributed, and the homogeneity of variance was not violated. The intraclass correlation coefficient (ICC) and the percentage coefficient of variation (%CV) are shown in Table 1. The ICC was excellent (Koo & Li, 2016) and ranged between 0.9 and 1.0 concerning the variables under study.

No statistically significant differences were found between the methods, except for TF50 ($p < 0.01$) and VF50 ($p < 0.01$). The effect size ranged from small to moderate concerning the variables that did not show statistically significant differences and it was considered as large for TF50 ($d = 1.4$) and VF50 ($d = 1.3$). Spearman's correlation was ranked between high and very high (Table 3). Moreover, no statistically significant differences between the obtained race times were found as it was determined by one-way ANOVA [(F(2,12) = 0.000, $p = 1.00$]. The heteroscedasticity test does not show variance in data dispersion.

Table 1. Intraclass correlation coefficient (ICC), percentage coefficient of variation (%CV), and 95% Confidence Interval (95% CI) between observations.

Variables	*n*	ICC	%CV	95% CI
ART (s)	8	1.00	0.1–1.7	1.00–1.00
ASR (spm)	8	0.99	0.4–2.0	0.995–1.00
AV ($m.s^{-1}$)	8	1.00	0.0–1.6	1.00–1.00
TF50 (s)	8	1.00	0.0–0.4	0.999–1.00
SRF50 (spm)	8	0.996	0.0–4.8	0.981–0.999
VF50 ($m.s^{-1}$)	8	1.00	0.0–0.8	0.999–1.00
TL50 (s)	8	1.00	0.0–0.7	0.998–1.00
SRL50 (spm)	8	0.999	0.0–4.4	0.993–1.00
VL50 ($m.s^{-1}$)	8	1.00	0.0–0.8	0.998–1.00
T100 (s)	25	0.999	0.0–1.1	0.994–0.999
SR100 (spm)	25	1.00	0.0–1.2	0.999–1.00
V100 ($m.s^{-1}$)	25	1.00	0.0–4.4	0.999–1.00

n: Number of observations, ART: Average race time; ASR: Average stroke rate; AV: Average velocity; TF50: Time at first 50 metres; SRF50: Stroke rate at first 50 metres; VF50: Velocity at first 50 metres; TL50: Time at last 50 metres; SRL50: Stroke rate at last 50 metres; VL50: Velocity at last 50 metres; T100: Time at 100 metres splits; SR100: Stroke rate at 100 metres splits; V100: Velocity at 100 metres splits.

Table 2. Mean values (±SD) and 95% confidence intervals for the means of kinematic variables in VID and GPS-ACC analysis.

		VID		GPS-ACC			
	n	Mean ± SD	95% CI	Mean ± SD	95% CI	*p*	*d*
ART (s)	8	68.39 ± 33.66	45.06–91.71	68.12 ± 33.89	44.64–91.61	0.08	0.7
ASR (spm)	8	126.63 ± 29.87	105.93–147.32	126.00 ± 29.37	105.64–146.36	0.38	0.3
AV ($m.s^{-1}$)	8	4.58 ± 0.59	4.17–4.99	4.61 ± 0.60	4.19–5.02	0.06	0.8
TF50 (s)	8	11.77 ± 1.25	10.90–12.64	11.41 ± 1.20	10.50–12.24	*<0.01	1.4
SRF50 (spm)	8	140.00 ± 25.07	122.63–157.37	141.63 ± 26.58	123.21–160.04	0.13	0.6
VF50 ($m.s^{-1}$)	8	4.29 ± 0.47	3.97–4.61	4.43 ± 0.47	4.10–4.75	*<0.01	1.3
TL50 (s)	8	11.75 ± 1.72	10.56–12.93	11.81 ± 1.87	10.52–13.11	0.40	0.3
SRL50 (spm)	8	115.50 ± 33.61	92.21–138.79	114.38 ± 32.89	91.58–137.17	0.08	0.7
VL50 ($m.s^{-1}$)	8	4.33 ± 0.60	3.92–4.74	4.32 ± 0.63	3.88–4.75	0.57	0.2
T100 (s)	25	21.88 ± 3.19	19.68–24.09	21.80 ± 3.19	19.59–24.01	0.16	0.3
SR100 (spm)	25	116.24 ± 32.90	93.44–139.04	115.72 ± 32.28	93.35–138.08	0.14	0.3
V100 ($m.s^{-1}$)	25	4.67 ± 0.71	4.18–5.16	4.69 ± 0.71	4.19–5.18	0.57	0.3

n: Number of observations, ART: Average race time; ASR: Average stroke rate; AV: Average velocity; TF50: Time at first 50 metres; SRF50: Stroke rate at first 50 metres; VF50: Velocity at first 50 metres; TL50: Time at last 50 metres; SRL50: Stroke rate at last 50 metres; VL50: Velocity at last 50 metres; T100: Time at 100 metres splits; SR100: Stroke rate at 100 metres splits; V100: Velocity at 100 metres splits; VID: video analysis; GPS-ACC: GPS/Accelerometer data; SD: standard deviation; 95% CI: 95% confidence intervals; *d*: Cohen effect size.
**alpha* <0.05.

The level of agreement between the VID and GPS-ACC analysis for kinematic variables is shown in Table 3. The data suggest the agreement between the methods, except for TF50 and VF50, with a more significant discrepancy of the limits of agreement around the mean being observed with a large amplitude between the upper and lower limits, and with a more considerable bias in these variables (TF50 = 0.4 ± 0.2 s, VF50 = –0.1 ± 0.1 $m.s^{-1}$) than in the analogous variables for the last 50 m (TL50 = –0.1 ± 0.2 s, VL50 = 0.0 ± 0.1 $m.s^{-1}$) and in the 100 m splits (T100 = 0.1 ± 0.3 s, V100 = 0.0 ± 0.1 $m.s^{-1}$).

In Figure 2, it is possible to observe the level of agreement in Bland-Altman scatter-plots concerning the average velocity and stroke rate for the total race, first and last 50 m and 100 m intermediate splits.

Table 3. Spearman's correlation and Bland-Altman analysis of the agreement between VID (video analysis) versus GPS-ACC (GPS/accelerometer).

	n	Bias	SD	LOA	r_s	*p*
VID versus GPS-ACC						
ART (s)	8	0.3	0.4	[−0.8, 1.3]	0.97*	<0.000
ASR (spm)	8	0.6	1.9	[−4.7, 6.0]	0.99*	<0.000
AV (m.s^{-1})	8	0.0	0.0	[−0.1, 0.1]	0.95*	<0.000
TF50 (s)	8	0.4	0.2	[−0.3, 1.0]	0.86*	<0.006
SRF50 (spm)	8	−1.6	2.7	[−9.2, 5.9]	0.89*	<0.003
VF50 (m.s^{-1})	8	−0.1	0.1	[−0.4, 0.2]	0.86*	<0.006
TL50 (s)	8	−0.1	0.2	[−0.7, 0.5]	0.97*	<0.000
SRL50 (spm)	8	1.1	1.6	[−3.2, 5.4]	0.99*	<0.000
VL50 (m.s^{-1})	8	0.0	0.1	[−0.2, 0.2]	0.97*	<0.000
T100 (s)	25	0.1	0.3	[−0.7, 0.9]	0.98*	<0.000
SR100 (spm)	25	0.5	1.7	[−4.3, 5.3]	0.99*	<0.000
V100 (m.s^{-1})	25	0.0	0.1	[−0.2, 0.2]	0.98*	<0.000

n: Number of observations, ART: Average race time; ASR: Average stroke rate; AV: Average velocity; TF50: Time at first 50 m; SRF50: Stroke rate at first 50 m; VF50: Velocity at first 50 m; TL50: Time at last 50 m; SRL50: Stroke rate at last 50 m; VL50: Velocity at last 50 m; T100: Time at 100 m splits; SR100: Stroke rate at 100 m splits; V100: Velocity at 100 m splits; SD: standard deviation; LOA: Limits of agreement; r_s: Spearman's correlation. *$p < 0.05$.

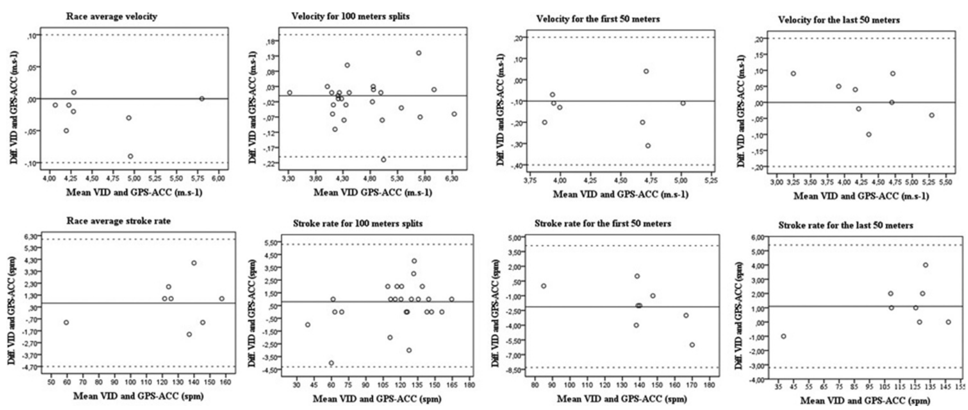

Figure 2. Differences (Diff.) between VID and GPS-Acc for the kinematic variables—velocity and stroke rate, for total race-distance, first and last 50 m, and splits of 100 m.

Discussion and implications

This study evaluated the validity of GPS-Acc technology usage (GPS 15 Hz, Acc 100 Hz) as opposed to VID to quantify kinematic variables (performance time, velocity, and stroke rate) in canoeing, by assessing kayaks and canoes of one, two, and four paddlers over different sprint distances (200 and 500 m). As far as we know, this work was the first to attempt a comparison analysis with both types of vessels in a real competition situation.

This paper's main finding was the agreement between the stroke rate analysis methods concerning all the distance splits (total race, 50 m start, intermediate 100 m splits, and 50 m finish). There was also agreement regarding the velocity analysis, except for the start of the race (first 50 m). This analysis took into consideration a broad spectrum of average velocities (3.20 and 6.65 m.s^{-1}) and stroke rates (31 and 168 spm) performed in a canoe sprint competition since it has assessed boats of one, two, and four paddlers on a canoe or kayak.

The results show that the GPS-Acc unit accurately recorded the stroke rate, at a considerable range of the SR, throughout the entire racecourse, regardless of whether it was the race start, intermediate splits, or the last metres before crossing the finish line. A significant increase in the SR from 0 to a high value defines the race start. This increment depends on the type of boat, the number of athletes, and the level of performance. With regard to the intermediate splits, the SR will depend on the race distance and the strategy adopted, besides the athlete's performance level. In the last metres of the race, in terms of the SR, what stands out is that the shortest the race distance, the more frequent is the chance of the athlete performing a stronger paddle stroke to launch the boat, trying to reach the finish line more quickly. Thus, Acc data have been demonstrated to obtain the SR accurately for kayak and canoe, regardless of the race stage, and irrespective of whether increasing, maintaining, decreasing, or even including the launch stroke at the end of the race.

In a study assessing velocity and stroke count data using a GPS-Acc unit, compared to data obtained from a concurrently recorded digital video of the performance, this unit proved to be a valid tool for stroke count quantification in breaststrokes and butterfly stroke (Beanland et al., 2014). In contrast, McDonnell et al. (2012), when studying canoeing, stated that the stroke rate should be evaluated with the VID for an accurate research in elite kayaker's performance since the SR data obtained by the GPS-Acc unit proved not to be valid for measuring stroke rate. These authors suggested that it should be used only when immediate feedback is valuable. On the contrary, our study suggests that the data from the GPS-Acc unit can be accurate and valid for evaluating stroke rate. The different conclusions between studies in canoeing may be due to the use of varying sampling rates, both in VID and in GPS-Acc. McDonnell et al. (2012) do not explain how, by means of the GPS-Acc unit, the data from the SR were extracted, therefore not allowing the comparison between methodologies. The compared analysis of the SR, between the two methods under analysis, can probably suggest that the accuracy considerably depends on the sampling rate of the technology used to collect the data, which, in this case, is higher for the Acc unit (100 Hz), compared to the video recording (30 Hz).

Evaluating stroke rate in canoeing is critical because this is the variable with the highest correlation with average kayak velocity and performance (Brown et al., 2011; Kendal & Sanders, 1992; McDonnell et al., 2013). Croft and Ribeiro (2013)have also suggested that the intensity zones could be defined only by stroke rate in training. Although the observed differences are not statistically significant, the analysis may be affected at the end of the race. For example, some athletes can 'launch' the boat by performing paddle strokes with durations different from the ones they normally do during the race, and, in some cases, even stopping paddling before the end of the race. This situation requires an extra care by the investigator/coach when interpreting the data.

The velocity variables in the analysis showed no differences between the two methods, thus confirming that the GPS can accurately determine race splits times and velocity. The results showed a non-significant tendency for overestimation of the GPS-Acc unit concerning the average velocity of the total race. In opposition to our findings, previous studies in kayaking (Janssen & Sachlikidis, 2010) and human locomotion either on foot (Townshend et al., 2008) or by bicycle (Witte & Wilson, 2004), have reported that GPS data tend to underestimate velocity. In 2004, Witte and Wilson suggested that the GPS technology limitation is that the satellite position may influence the accuracy of the velocity measures. However, technological advances have increased the number of satellites used to triangulate and calculate position and the sample rate increase, thus improving data accuracy. Recent studies (Bataller-Cervero et al., 2019; Beato et al., 2018), using different methodologies in field-based activities, have demonstrated the use of GPS as an accurate alternative to recording straight-line velocity.

The VID may have had greater accuracy for assessing velocity in the present study because its sampling rate was 30 Hz, which was higher than the one of the GPS unit (15 Hz). In terms of velocity, one aspect that can influence the compared analysis is the paddler's reaction time to the starting signal. For the race start analysis, by means of the VID, the movement of the starting bucket was taken into consideration. For the GPS analysis, it was considered the index in which the velocity changed from 0 to a positive value since it was not possible to determine in these data when the starting bucket was activated. In a study with elite sprinters, Tønnessen et al. (2013) stated that reaction abilities affect sprint performance since reaction time on stationary starts may have a noticeable influence on velocity data and, consequently, on performance. Thus, the significant differences observed between the methods used for time and velocity at the first 50 m may be because the VID took into account the official start, which was defined by the movement of the starting bucket. The GPS-Acc data were based on the boat's changing of velocity from 0 to a higher value, thus removing the impact of the athlete's reaction time.

One of the advantages of using GPS technology is that it enables a quick post-event analysis of the kinematic variables under study (McDonnell et al., 2012). Then, based on the estimates resulting from that analysis, other variables of interest include the distance per stroke and the stroke index. This quickness can be crucial in competition, enabling the race strategy analysis immediately after heat, semi-final, and final, taking into consideration that canoe sprint race regulations do not allow athletes to use devices that show them real-time kinematic data. Furthermore, GPS technology has the advantage of enabling to choose from different distance splits according to the investigators/coaches' interests. However, although they enable quick feedback, the data obtained by the GPS-Acc analysis do not enable other kinematic analyses of the paddling technique that the VID does, such as linear and angular kinematics of the different phases of the paddling stroke.

A limitation of the study is that it reports to data collected by a GPS-Acc in canoe sprint races performed in the northern hemisphere, specifically in the European territory (Portugal), which can influence the number of satellites used for triangulation beyond the impact of the time of the day on the GPS data, as reported by Janssen and Sachlikidis (2010). Future investigations should use units from other brands to verify the validity of their use in canoe sprint and other territories. In addition, this study uses different VID and GPS-Acc sampling rates to analyse the variables, considering that the available GPS technology is limited to around 15 Hz. Another limitation is the possible video error sources due to the parallax effect. Finally, given the data analysis, the fact that different indexes were considered regarding the start of the race, in the VID it was the official start and in the GPS-Acc unit it was the boats' movement start, could also have limited the comparison.

The agreement observed concerning the variables related to the SR is the main finding of this research. The SR is one of the most used variables to define training intensity and is the variable most correlated with performance. These results suggest the GPS-Acc unit as a valuable and accurate solution to assess time and velocity variables. In terms of the SR assessment, it could have been even more reliable than the VID due to the high rate of data analysis. GPS-Acc devices can considerably reduce the time analysis demanded by the VID and facilitate the analysis of the training sessions, competition velocity, SR, and other variables estimated from these. The device with a higher sampling rate could be more accurate (VID—30 Hz and GPS—15 Hz), as verified in the present study concerning time and velocity variables. However, the GPS-Acc, even so, showed a high agreement with the VID. Thus, considering the needs of researchers and coaches, the use of both methods could be of interest. The GPS-Acc unit, because it enables to measure the variables analysed in this study with quickness and accuracy, and the VID whenever a more detailed analysis of the paddling technique is required.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported that there is no funding associated with the work featured in this article.

ORCID

Rui António Fernandes http://orcid.org/0000-0002-5355-1944
Fernando Alacid http://orcid.org/0000-0001-6126-5289
Beatriz Branquinho Gomes http://orcid.org/0000-0003-2885-7666

References

Alacid, F., Ferrer, V., Martínez, E., & Carrasco, L. (2005). Quantitative analysis of the technique of paddling in infant kayakers. *Motricidad: European Journal of Human Movement*, *13*, 133–146.

Aughey, R. J. (2011). Applications of GPS technologies to field sports. *International Journal of Sports Physiology and Performance*, *6*(3), 295–310. https://doi.org/10.1123/ijspp.6.3.295

Bataller-Cervero, A. V., Gutierrez, H., Derentería, J., Piedrafita, E., Marcén, N., Valero-Campo, C., Lapuente, M., & Berzosa, C. (2019). Validity and reliability of a 10 Hz GPS for assessing variable and mean running speed. *Journal of Human Kinetics*, *67*(1), 17–24. https://doi.org/10.2478/hukin-2018-0084

Beanland, E., Main, L. C., Aisbett, B., Gastin, P., & Netto, K. (2014). Validation of GPS and accelerometer technology in swimming. *Journal of Science and Medicine in Sport*, *17*(2), 234–238. https://doi.org/10.1016/j.jsams.2013.04.007

Beato, M., Devereux, G., & Stiff, A. (2018). Validity and reliability of global positioning system units (STATSports Viper) for measuring distance and peak speed in sports. *Journal of Strength & Conditioning Research*, *32*(10), 2831–2837. https://doi.org/10.1519/JSC.0000000000002778

Bifaretti, S., Bonaiuto, V., Federici, L., Gabrieli, M., & Lanotte, N. (2016). E-kayak: A wireless DAQ system for real time performance analysis. *Procedia Engineering*, *147*, 776–780. https://doi.org/10.1016/j.proeng.2016.06.319

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *The Lancet*, *1*(8476), 307–310. https://doi.org/10.1016/S0140-6736(86)90837-8

Bland, J. M., & Altman, D. G. (1990). A note on the use of the intraclass correlation coefficient in the evaluation of agreement between two methods of measurement. *Computers in Biology and Medicine*, *20*(5), 337–340. https://doi.org/10.1016/0010-4825(90)90013-F

Bonaiuto, V., Gatta, G., Romagnoli, C., Boatto, P., Lanotte, N., & Annino, G. (2020). A pilot study on the e-kayak system: A wireless DAQ suited for performance analysis in flatwater sprint kayaks. *Sensors*, *20*(2), 1–17. https://doi.org/10.3390/s20020542

Brown, M. B., Lauder, M., & Dyson, R. (2011). Notational analysis of sprint kayaking: Differentiating between ability levels. *International Journal of Performance Analysis in Sport*, *11*(1), 171–183. https://doi.org/10.1080/24748668.2011.11868538

Cohen, J. (1988). *Statistical power analysis for the behavioral science* (2nd ed.). Lawrence Erlbaum Associates.

Coutts, A. J., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport*, *13*(1), 133–135. https://doi.org/10.1016/j.jsams.2008.09.015

Croft, H., & Ribeiro, D. C. (2013). Developing and Applying a Tri-axial Accelerometer Sensor for Measuring Real Time Kayak Cadence. *Procedia Engineering*, *60*, 16–21. https://doi.org/10.1016/j.proeng.2013.07.038

Fleming, N., Donne, B., Fletcher, D., & Mahony, N. (2012). A biomechanical assessment of ergometer task specificity in elite flatwater kayakers. *Journal of Sports Science & Medicine*, *11*(1), 16–25.

Gomes, B. B., Conceição, F. A. V., Pendergast, D. R., Sanders, R. H., Vaz, M. A. P., & Vilas-Boas, J. P. (2015). Is passive drag dependent on the interaction of kayak design and paddler weight in flat-water kayaking? *Sports Biomechanics*, *14*(4), 394–403. https://doi.org/10.1080/14763141.2015.1090475

Gomes, B. B., Mourão, L., Massart, A., Figueiredo, P., Vilas-Boas, J. P., Santos, A. M. C., & Fernandes, R. J. (2012). Gross efficiency and energy expenditure in kayak Ergometer exercise. *International Journal of Sports Medicine*, *33*(8), 654–660. https://doi.org/10.1055/s-0032-1301907

Gomes, B. B., Ramos, N. V., Conceição, F., Sanders, R., Vaz, M., & Vilas-Boas, J. P. (2020). Paddling time parameters and paddling efficiency with the increase in stroke rate in kayaking. *Sports Biomechanics*, 1–9. https://doi.org/10.1080/14763141.2020.1789204

Goreham, J. A., Landry, S. C., Kozey, J. W., Smith, B., & Ladouceur, M. (2020). Using principal component analysis to investigate pacing strategies in elite international canoe kayak sprint races. *Sports Biomechanics*, 1–16. https://doi.org/10.1080/14763141.2020.1806348

Harrison, S. M., Cleary, P. W., & Cohen, R. C. Z. (2019). Dynamic simulation of flat water kayaking using a coupled biomechanical-smoothed particle hydrodynamics model. *Human Movement Science*, *64*, 252–273. https://doi.org/10.1016/j.humov.2019.02.003

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine*, *30*(1), 1–15. https://doi.org/10.2165/00007256-200030010-00001

Janssen, I., & Sachlikidis, A. (2010). Validity and reliability of intra-stroke kayak velocity and acceleration using a GPS-based accelerometer. *Sports Biomechanics*, *9*(1), 47–56. https://doi.org/10.1080/14763141003690229

Kendal, S. J., & Sanders, R. H. (1992). The technique of elite flatwater kayak paddlers using the wing paddle. *International Journal of Sport Biomechanics*, *8*(3), 233–250. https://doi.org/10.1123/ijsb.8.3.233

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Larsson, P. (2003). Global positioning system and sport-specific testing. *Sports Medicine*, *33*(15), 1093–1101. https://doi.org/10.2165/00007256-200333150-00002

Le Sage, T., Bindel, A., Conway, P. P., Justham, L. M., Slawson, S. E., & West, A. A. (2011). Embedded programming and real-time signal processing of swimming strokes. *Sports Engineering*, *14*(1), 1–14. https://doi.org/10.1007/s12283-011-0070-7

Limonta, E., Squadrone, R., Rodano, R., Marzegan, A., Veicsteinas, A., Merati, G., & Sacchi, M. (2010). Tridimensional kinematic analysis on a kayaking simulator: Key factors to successful performance. *Sport Sciences for Health*, *6*(1), 27–34. https://doi.org/10.1007/s11332-010-0093-7

McDonnell, L. K., Hume, P., & Nolte, V. (2012). Sprint kayaking stroke rate reliability, variability and validity of the Digitrainer accelerometer compared to Gopro video measurement. In E. J. Bradshaw, A. Burnett, and P. A. Hume (Eds.), *Proceedings of the 30th International Conference of the International Society of Biomechanics in Sports* (vol., 98, pp. 316–319). Melbourne, Australia.

McDonnell, L. K., Hume, P., & Nolte, V. (2013). A deterministic model based on evidence for the associations between kinematic variables and sprint kayak performance. *Sports Biomechanics*, *12*(3), 205–220. https://doi.org/10.1080/14763141.2012.760106

Mukaka, M. M. (2012). Statistics corner: A guide to appropriate use of correlation coefficient in medical research. *Malawi Medical Journal*, *24*(3), 69–71.

Scott, M. T., Scott, T. J., & Kelly, V. G. (2016). The validity and reliability of global positioning systems in team sport: A brief review. *Journal of Strength & Conditioning Research*, *30*(5), 1470–1490. https://doi.org/10.1519/JSC.0000000000001221

Siirtola, P., Laurinen, P., Roning, J., & Kinnunen, H. (2011). Efficient accelerometer-based swimming exercise tracking. In *IEEE SSCI 2011: Symposium Series on Computational Intelligence - CIDM 2011: 2011 IEEE Symposium on Computational Intelligence and Data Mining* (pp. 156–161). Paris, France. https://doi.org/10.1109/CIDM.2011.5949430

Sperlich, J., & Baker, J. (2002). Biomechanical testing in elite canoeing. In K. E. Gianikellis (Ed.), *20th International Symposium on Biomechanics in Sports* (pp. 44–47). Cáceres, Spain.

Thomas, O., Sunehag, P., Dror, G., Yun, S., Kim, S., Robards, M., Smorla, A., Green, D., & Saunders, P. (2010). Wearable sensor activity analysis using semi-Markov models with a grammar. *Pervasive and Mobile Computing*, *6*(3), 342–350. https://doi.org/10.1016/j.pmcj.2010.01.002

Tønnessen, E., Haugen, T., & Shalfawi, S. A. I. (2013). Reaction time aspects of elite sprinters in athletic world championships. *Journal of Strength and Conditioning Research*, *27*(4), 885–892. https://doi.org/10.1519/JSC.0b013e31826520c3

Townshend, A. D., Worringham, C. J., & Stewart, I. B. (2008). Assessment of Speed and Position during Human Locomotion Using Nondifferential GPS. *Medicine & Science in Sports & Exercise*, *40*(1), 124–132. https://doi.org/10.1249/mss.0b013e3181590bc2

Vaquero-Cristóbal, R., Alacid, F., López-Plaza, D., Muyor, J. M., & López-Miñarro, P. A. (2013). Kinematic variables evolution during a 200-m maximum test in young paddlers. *Journal of Human Kinetics*, *38*, 15–22. https://doi.org/10.2478/hukin-2013-0041

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). John Wiley & Sons.

Witte, T. H., & Wilson, A. M. (2004). Accuracy of non-differential GPS for the determination of speed over ground. *Journal of Biomechanics*, *37*(12), 1891–1898. https://doi.org/10.1016/j.jbiomech.2004.02.031