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Kilian Philippe[1], Thierry Paillard[1], Romain Dubois[1], Olivier Maurelli[2] & Jacques Prioux[3].

[1]Laboratory of Movement, Balance, Performance and Health (MEPS, EA-4445), University of Pau and Pays de l'Adour, Tarbes, France.

[2] Laboratory of Muscular Dynamism and Metabolism (UMR-866), University of Montpellier, France.

[3] Movement, Sport and Health laboratory (EA-1274), Faculty of sport science, Rennes, France.

Corresponding author

Kilian Philippe

Tel : + (33) 6 59 39 70 56

Email : kilian.philippe@yahoo.fr

Linkedin : Kilian Philippe

Abstract

This study aimed to determine the key performance indicators of inshore sailing during the sailing Tour de France. Technical and physical parameters were investigated to determine the discriminating factors between successful and less successful international level sailors. Measurements from 21 sailors (mean ± SD; age = 23.81 ± 4.18 years) were conducted prior to the sailing Tour de France. Global Positioning System data of all participating teams (n=23) was analyzed. Sailors were divided in two groups (i.e. successful and less successful) according to qualifying performance percentage. The differences between successful and less successful sailors were explored by means of independent t-tests. Results indicate that successful boats displayed higher maximal speed, higher average speed and more efficient starting performance per race than less successful boats. Successful sailors have stronger handgrip strength, higher isometric maximal voluntary force relative to bodyweight (isometric mid-thigh pull) and more powerful submaximal pulling (bench pull) actions than their less successful counterparts. The results of this study suggest that multiple sailing, physical and physiological variables are related to sailing performance in inshore sailing. Therefore, we emphasize the importance of integrating specific testing protocols to evaluate the performance potential of inshore sailors participating in the sailing Tour de France.

Keywords: Sailing, Tour de France, Elite Athletes, Inshore sailing.

Introduction

This study focuses on inshore sailing performance in multihull-crewed vessels. The sailing tour de France (TDF) is one of Europe's major annual inshore sailing event. For over 40 years, this competition has allowed some of the world's best sailors to compete along the French coastline. Today, the competition sees teams engage in regattas aboard the Diam24 One Design (D24) trimaran.

The D24 vessel is 7.5 m long, 5.62 m wide, has a mast height of 11.5 m, a total sail area of 70 m² and is primarily made of composite material. It is maneuvered by three highly skilled sailors; helmsman, trimmer and bowman (Figure 1). During the TDF, the boat competes in different stages; the "nautical stadium" (NS; n=10) and "coastal raid" (CR; n=5) events. A NS is a short but intense stage that consists of qualification heats (2-6 per NS day). Teams race to tally points in the aim to qualify for the daily final (Figure 2). The boats are sailed in a fleet-race format (i.e. two groups of 11-12 teams) around a 1-3 lap (according to committee) beam reach, downwind and upwind course of 2672.9 ± 610.3 m. The best four teams of each fleet are selected to advance to the daily final. A CR is an event that tests the sailor's ability to race on larger and longer courses (59100 ± 19400 m) upon the coastline.

Although the TDF has established its' importance in the sailing environment, performance studies are still scarce in sports literature. This is partly due to two distinguishing external parameters that make such analysis unsteady. First, the TDF is unique in that the format changes annually according to host cities participating to the edition. The influence of geographical location has a significant impact on uncontrollable parameters such as weather and sea conditions. Second, the ever-evolving development of technology and hydrodynamic research leads to constant changes of the official TDF vessel. This ultimately influences the conditions specific to the race. Nevertheless, despite the singular nature of the TDF, it would be interesting to collect data relative to sailing events (i.e., race task analysis) and qualities required (i.e., key performance indicators) in order to better prepare athletes for this sport competition.

Sport performance requires the optimal exploitation of the athletes' potential, but little is known about the contribution of different factors (i.e. physiological, psychological, technical and tactical/strategic) in sailing performance. To date, it was mainly reported that sailing is a sport for which bio-informational and strategic qualities are fundamental (Araújo et al., 2015). Although the anthropometric, physical and physiological characteristics are essential to performance in most sports, their influence on sailing performance still remains to be analyzed. Establishing normative data, by engaging in profiling approaches, would be a valuable mean to understanding the needs for optimizing sport specific performance. Such data would be promoting a better understanding for identifying talent (Roczniok et al., 2013), determining an athlete's strengths and weaknesses (Duthie, 2006), guiding tactical choices (Fernandez-Fernandez et al., 2009) and elaborating sport-specific strength and conditioning programs. Therefore, the purpose of this study was to: (1) document the nature and technical key performance indicators of the TDF; (2) provide insights into the anthropometric, physical and physiological characteristics of elite inshore sailors. We hypothesized that sailing performance factors (e.g., distance covered at different sailing speeds) and anthropophysiological characteristics would be identified and contribute to racing success and ranking.

Materials and methods

Subjects

Professional male international inshore sailors (N = 21; mean ± SD; age = 23.81 ± 4.18 years; height = 179.32 ± 7.30 cm; body mass = 74.78 ± 6.56 kg) were assessed in the final preparation phase leading up to the 2019 TDF. Subjects were informed of the testing procedures, potential risks and the purpose of their participation. All subjects had already competed in international competitions. Their collective experience included 59 TDF campaigns. At the time of testing, the subjects had completed 6 months of sailing training and had been actively participating in strength and conditioning programs for at least three years. None of the participants reported injuries or diseases that would impair their physical performance. The study protocol was approved by the ethics committee of Rennes University. Written informed consent was obtained from all participants before the start of the study. In this study, criteria used to qualify an athlete's performance was based on the team's final ranking. An athlete was categorized as "successful" (SA, n=10) if he crewed a successful boat (SB). Less successful athletes (LSA, n=11) crewed a less successful boat (LSB).

Procedures

Subjects were signed up for 2 testing sessions: a) anthropometry and b) physical and physiological. Both a) and b) testing sessions were completed on the same day. Subjects were instructed to rest adequately 72 hours before testing and to maintain normal eating and drinking habits during this period. The first session consisted of anthropometric measurements. These measurements took place in the morning upon waking up. Athletes were asked to refrain from eating two hours prior to testing and to avoid caffeine consumption twelve hours before. The second session was directed towards evaluating the physical and physiological components. The testing took place two hours post breakfast. The subjects were asked to not change their nutritional habits during this meal. Before all testing, a standardized warm-up was completed including jogging, dynamic movements, and stretches. Each physical and physiological quality measured was fully explained and demonstrated before testing.

Regatta analysis

The 42nd sailing Tour de France took place in July 2019 and was held in 7 French coastal cities. This edition was disputed between 23 international teams over 17 days (10 NS and 5 CR) interspersed by two days of recovery. This resulted in 99 races (84 qualifying heats, 10 finals and 5 CR). Points were attributed daily according to results (i.e.: 1st receives 50 points, 2nd receives 49… last receives 28) and were accumulated throughout the competition. The final ranking established the winner of the TDF.

Race data – including sailing distance (m), average speed ($m.s^{-1}$), maximal speed ($m.s^{-1}$), course coverage (%) (i.e., distance sailed / course distance), start performance (rank and time gap at the first mark) and maneuvers (tack and gybe; count) – were collected during all 84 qualifying heats and 5CR. GPS units (Mylaps® X5 Global Positioning System; 9-channel GPS receiver; location measurement accuracy 2.5 m; dimensions 109 × 59 × 22 mm; weight 95 g; temperature range –20 – +55°C) were placed on all of the 23 boats. A boat was categorized as “successful” (SB, n=7) if it qualified for more than half of the daily finals. Less successful boats (LSB, n=16) qualified for half or less of the daily finals.

Anthropometric, physical and physiological assessment

Session 1: Anthropometric measurement.

Anthropometric characteristics were measured in the following order: weight, height, sitting height, wingspan, skinfolds and body girths. A weighing scale (Seca®, Hamburg, Germany) and a stadiometer (Seca®, Barcelona, Spain) were used to measure weight and height respectively. Measurements for height (standing and sitting) and weight were made with an accuracy of 0.5 cm and 0.1 kg respectively. Wingspan was measured to the nearest 0.1 cm, from one middle fingertip to the other using a measuring tape (Seca®, Barcelona, Spain). Three skinfolds were taken on the right side of each participant (pectoral, abdominal and thigh) according to recommendations by Jackson and Pollock (Jackson and Pollock, 1978). The skinfolds were measured with a Harpenden skinfold caliper (Harpenden®, Burgess Hill, UK) with 10-g.mm^{-2} of constant pressure. Body density was assessed (Jackson and Pollock, 1978) while body fat was calculated using Brozek's equation (Brozek et al., 1963). A measuring tape (Seca®, Barcelona, Spain) was used to measure the girth of relaxed arms, thighs and calves on left and right sides following measuring recommendations of the international society for the advancement of kinanthropometry (ISAK; Marfell-Jones et al., 2006).

Session 2: Physical testing.

Physical and physiological characteristics were measured in randomized order.

Handgrip strength. Maximal isometric hand-grip strength (HGS) was assessed with a Jamar® handgrip dynamometer (Sammons Preston Corp., Bolingbrook, Ill., USA). The test positions were standardized (Svantesson et al., 2009). Three trials were performed on each hand. The first three trials started with the right hand. Subjects were instructed to squeeze the device as hard as possible for 3 s. The time between each trial was 15 s and 3 min of rest was allowed when changing hands. The maximal measure of the three trials was retained in kilograms (Kg). Sum (HGS_{sum}) of both hands and dominant hand (HGS_{dom}) measures were assessed and included in the results.

<u>Vertical jumps.</u> Lower body power was tested on the squat jump (SJ) and countermovement jump (CMJ) using a chronojump contact mat (Chronojump-Boscosystem™, Software, Spain). Each subject had three attempts per jump with 1 min of rest between trials. Subjects started with SJ and, after a 3 min passive recovery, were assessed on CMJ. Instructions for the jumps were explained and controlled with a goniometer for the SJ. Subjects were instructed to descend to 90° knee flexion. Once position was reached, a countdown of "3, 2, 1, jump" was indicated orally. A validated and reliable smartphone application (Balsalobre-Fernandez et al., 2015) was used for lateral video analysis. This allowed to track lateral kinematics and thus avoid collecting results that involved a countermovement action. Both the SJ and CMJ were done with subjects placing hands on their hips as to avoid arm movement. For the CMJ, athletes were instructed to perform a rapid eccentric phase, immediately followed by a rapid concentric phase with the intention to jump as high as possible. Height and peak power of the best SJ (SJ_H and SJ_{PP}) and CMJ (CMJ_H and CMJ_{PP}) performances were reported for analysis.

<u>Isometric mid-thigh pull</u>. Testing for isometric mid-thigh pull (IMTP) was conducted on a customized pulling rack apparatus specifically developed for data collection. IMTP was performed using two portable force platforms sampling at 1000 Hz (Pasco™, Rosedale, USA) and previously validated (Peterson Silveira et al., 2017). The force plates were connected to a portable laptop running the Capstone Software Program (Pasco™, Rosedale, USA). Knee angle was measured with a goniometer, to ensure a range of 125-140° (Haff et al., 2013). The bar height was adjusted to meet the testing criteria and to accommodate to the athlete's size. Once the test had been thoroughly described and testing parameters were set, a specific warm-up was conducted. Athletes were provided with two warm-up pulls, 1 at 50 % and 1 at 75 % of perceived maximum effort, separated by 1 min of rest. Once body position was stabilized (verified by observation and live force measures), the subject was given a countdown of "3, 2, 1, pull." Minimal pre-tension was allowed to ensure that there was no slack in the subject's body before initiation of the pull. Athletes performed 3 maximal IMTP with the instruction to pull the bar with maximal effort

as quickly as possible and push the feet down into the force platform. The time between each trial was 1 min. Each maximal isometric trial was performed for 5 s. The best trial was used for data collection and was analyzed relatively to the athlete's body weight ($IMTP_W$).

Force-velocity pulling profile. Force-velocity curve testing on the bench-pull (BP) was conducted on an elevated bench-pull device placed above a guided squat rack (Smith machine). The Smith machine (Technogym®, Cesena, Italy) allowed for vertical displacement through guided rods. A Chronojump linear position transducer (Chronojump™, Barcelona, Spain) was placed below the bar and automatically calculated the kinematic parameters of every repetition. Subjects were instructed to pull the bar with maximum effort until the barbell hit the bench 8 cm below the subject's chest. The barbell was then lowered and a brief pause of 1 s was observed to avoid the rebound effect or any stretch-shortening cycle interference. The protocol followed Sanchez-Medina's instructions (Sanchez-Medina et al., 2014). Initial load started at 20 kg and increased by increments of 10 kg until mean propulsive velocity (BP_{MPV}) was lower than 0.7 m.s^{-1}. Three attempts were executed for light (< 50 % 1RM), 2 for medium (50–80 % 1RM) and only 1 for the heaviest (> 80 % 1RM) loads. Inter-set rest intervals were 3 min for the light and medium loads and 5 min for the heaviest loads. The fastest bar speed for each load was recorded. The maximum load that could be lifted once was considered the athlete's 1RM (BP_{1RM}). BP_{MPV} was calculated for the loads that were completed by all subjects (BP_{MPV20}, BP_{MPV30}, BP_{MPV40} and BP_{MPV50}).

Anaerobic capacity. Anaerobic capacity was tested using a modified rowing Wingate test (MRWT) on a rowing ergometer Concept II-D (Concept 2 INC™, Vermont, USA). The flywheel was set at 130 drag factor. Subjects were allowed 3 min of warm-up at a rate of perceived exertion of 5 out of 10. Athletes then completed the 30 s all-out test. Exercise performance was expressed as mean power output (MPO) in watts (W) and was calculated automatically by Concept II-D. The procedure has been described previously (Riechman et al., 2002).

Maximal oxygen uptake. Maximal oxygen uptake ($\dot{V}O_{2max}$) was assessed through a step incremental test (MOU_{T25}) on an electromagnetically braked cycle ergometer (Kettler®

Ense-Parsit, Germany). $\dot{V}O_{2max}$, expressed as $ml.min^{-1}.kg^{-1}$, measures were collected through the use of a portable self-contained metabolic cart CardioCoach (Korr Medical Technologies®, Salt Lake City, UT) and previously validated (Dieli-Conwright et al, 2009). Subjects were given time to adjust seat and bar height before starting the test. MOU_{T25} started at 20 W and increased by 25 $W.min^{-1}$ until voluntary exhaustion (Amann et al., 2004). A cadence of 90-100 RPM was standardized throughout the test. During the MOU_{T25} the following variables were constantly registered: heart rate (HR), minute ventilation ($\dot{V}_E$) and oxygen uptake ($\dot{V}O_2$). Prior to each test, the gas analyzer was calibrated according to the manufacturer's specifications. $\dot{V}O_{2max}$ was determined when physical signs suggestive of exhaustion were apparent and at least one of the following two criteria were met; (1) HR_{max} was no less than 15 beats below the predicted maximum [220 – (0.65 x age); Spiro 1977] and (2) a steady state of $\dot{V}O_2$ despite an increase in workload (Vehrs et al., 2007).

Statistics

Data was calculated through standard statistical methods and are presented as mean ± standard deviation. All variables were considered normally distributed through analysis with the Shapiro-Wilk test, histograms and skewness values prior to analysis. One-way analysis of variance (ANOVA) was used to compare anthropometric, physiological and physical measures for the different crew positions. Independent t-tests were performed to determine if significant differences existed between physical profiles (SA vs. LSA) and technical parameters (SB vs. LSB). When results were significantly different, an effect size (ES) calculation was used. ES was evaluated using Cohen's d along with 95% confidence intervals. ES of ≤0.2, 0.21-0.60, 0.61-1.20, 1.21-2.0, ≥2.0 were considered as trivial, small, moderate, large and very large, respectively (Batterham and Hopkins 2006). Finally, Spearman's Rank Order Correlation (r) was used to identify the relationship between outcome (race and overall standings) and the key performance indicators identified as significant in the independent t-tests. Statistical analyses were performed using the SPSS package (15.0 version; SPSS, Inc., Chicago, IL, USA). The level of significance was set at $p<0.05$.

Results

Regatta analysis

Mean race duration was 17 ± 2 min for NS and 244 ± 35 min for CR. Course distance was 2672.9 ± 610.3 m for NS and 59000 ± 17500 m for CR. Teams participated between 47 and 57 races and accumulated 474.3 ± 38.3 maneuvers (NS: 355.1 ± 37.8; CR: 119.1 ± 6.6). Gybes (downwind maneuver; lasted ~12 s) were more recurrent than tacks (upwind maneuver; lasted ~8 s), respectively 259.3 ± 26.8 vs. 214.9 ± 26.1. Maneuver count per NS heat was 8.7 ± 0.9 and 23.8 ± 1.3 for CR. Sailing distance for NS heats was 4161.8 ± 80.1 m and 78500 ± 34900 m for CR. Course coverage for NS was 158.5 ± 3.0 % and 133.8 ± 4.9 % for CR.

Technical key performance indicators

Sailing parameters collected during the TDF are analyzed in Table 1 for SB, LSB and all boats. Race outcome for NS was significantly correlated ($p<0.01$) with starting performance ($r=.52$), maximal speed ($r=.33$) and average speed ($r=.76$). Coastal raid ranking was correlated ($p<0.01$) with starting performance ($r=.58$), maximal speed ($r=.43$) and average speed ($r=0.81$). All three of the highlighted performance parameters were also significantly correlated to final rankings of the TDF.

Profiling and physical key performance indicators

Table 2 shows mean (± SD) for the age and anthropometric characteristics of professional male TDF sailors. No significant differences were observed in anthropometric parameters between crew positions (Table 2) and success attribute. The physical and physiological profiles of sailors are reported in Table 3. Successful sailors had stronger HGS_{Dom} (ES=0.82) and $IMTP_W$ relatively to body weight (ES=0.93) and exerted faster BP_{MPV20} (ES=1.18) than their less successful counterparts. The differences between SA and LSA were significant ($p=0.001$). HGS_{Dom} ($r=0.54$), $IMTP_W$ ($r=0.41$) and BP_{MPV20} ($r=0.61$) were significantly correlated ($p<0.01$) to rank in NS heats. CR results were correlated to HGS_{Dom} ($r=0.37$; $p<0.05$) and BP_{MPV20} ($r=0.74$; $p<0.01$). BP_{MPV20} showed strong correlation with final TDF rankings ($r=0.8$; $p<0.05$).

Discussion

The aim of this present study was threefold. First, our objective was to analyze and report the nature of sailing during the TDF. Second, we attempted to identify the key performance indicators associated with racing outcome. Third, we directed a descriptive analysis of anthropometric, physical and physiological profiles of elite level sailors participating in the TDF. Most prominently, the analysis has indicated the capacity to discriminate between SB/LSB and SA/LSA by considering technical and physical parameters.

Regatta analysis

This is the first report on the nature of sailing during the TDF. Overall, sailors travelled 541300 ± 64900 m in 1792.3 ± 409.3 min during the 15 days of competition. Mean race duration (SN: 17 min; CR: 244 min) and the number of maneuvers were highly variable due to external parameters (e.g. race course and tactics, environmental condition). Insights on the nature of energetic demands and work to rest ratio can nevertheless be estimated. In sailing, particularly where sailors must hike, work to rest ratio should be re-evaluated as a dynamic to static effort ratio. Tacking maneuvers lasted around 8 s while a gybe lasted around 12 s. High intensity efforts, linked to the demands of maneuvering (Neville et al., 2009), occurred on a 1:14 ratio in NS and 1:50 in CR. Dynamic to static ratio reached as high 1:10 when boats chose to sail a course close to shoreline (CR). Hence, it can be assumed that the anaerobic energy system is significantly stressed during TDF racing. However, the TDF competition also requires a good aerobic level to endure the 15 days of sailing and to optimize recovery when racing (NS: 77 ± 14 $min.stage^{-1}$; CR: 244 ± 35 $min.stage^{-1}$).

Technical key performance indicators

GPS technology permits performance analysts to monitor external training load (Cummins et al., 2013) and collect data to identify technical and tactical performance indicators in sailing activities (Perez Turpin et al. 2009). Research has identified the key technical performance indicators in windsurfing (Anastasiou et al., 2019), match racing

(Neville et al., 2009) and kiteboarding (Caimmi and Samprini, 2017). To the best of our knowledge, this is the first study to analyse such parameters in fleet racing.

With regards to our results, we observed variability in the distance covered and time to finish a heat. Wind direction and wind speed influences the organisation committee in course settings (Perez Turpin et al., 2009). Nevertheless, it should be noted that sailing also relies on cognitive skills (Araújo et al., 2015) and that different racing strategies exist. Teams must regularly analyse weather and oceanographic reports to determine the most appropriate course (Thill, 1982). Other external parameters (e.g., position in the fleet, changes of racing conditions, placement of opponents on course) can provoke variations and modifications in initial strategy (Araujo and Sepra, 1997; Ward, Williams and Bennett, 2002; Manzanares, Segado and Menayo, 2012).

Speed parameters have previously discriminated between successful and less successful athletes in other sailing competitions (Anastasiou et al., 2019; Caimmi and Samprini, 2017). This comforts our findings in that both average speed and maximal speed were significantly correlated to both race and TDF overall outcome. On the basis of bio-informational data, one can assume that SB were more efficient in determining the most favourable course to take in order to optimize boat speed. Pluijms et al. (2015) have investigated the difference in visual fixation behaviour between top and bottom-ranked sailors. On the one hand, bottom ranked sailors focus their centre of attention on the boat and thus might discard important environmental information. On the other hand, top ranked sailors, were capable of "feeling" the changes in boat speed and direction through mechanical and proprioceptive feedback. SB also displayed better starting performance (rank and time gap at first mark) than LSB. Starting performance was significantly correlated with race outcome and overall TDF ranking. This could be due to sailors changing their gaze to look for relevant environmental information that might enhance the boat's performance (Pluijms et al., 2015). Indeed, if boats arrived first at the first mark they would not have to account for other information concerning opposing team position.

Profiling and physical key performance indicators

Although sailing has acquired research interest through important international events (i.e. Americas Cup and Olympic Games), none has analyzed the anthropometric, physical and physiological demands for multihull fleet racing. Hence, we can only compare our data to those of similar sailing events. The mean data for height and weight of the 21 subjects (179.3 ± 7.3 cm and 74.8 ± 6.6 kg) are different to those found in other studies. Indeed, offshore sailors tended to be smaller and heavier (177 ± 7 cm and 78 ± 10 kg; Hurdiel et al., 2014) whilst measures reported on the 2002 TDF outlined the smaller and lighter profiles of sailors at the time (173 ± 6 cm and 62.6 ± 9.3 kg; Leger et al., 2008). The body fat of athletes in the study hereby (12.91 ± 4 %) was similar to previously reported data of America's Cup sailors (13 ± 4 %; Neville et al., 2009), and seems within the range (10-15%) of international and Olympic dinghy sailors (Vangelakoudi et al., 2007; Bojsen-Moller et al., 2007). Anthropometric characteristics vary according to competitive status, crew position, publishing date and sailing classification (Larsson et al., 1996). Surprisingly, there was no significant difference in anthropometric data in regards to crew position (Table 2). This could be the result of the race organization's choice to set the minimal total crew weight to 210 kg and supports findings by Neville et al., 2009 that highlights the modern sailors' strategy to reduce body fat of the whole crew as to maximize lean muscle mass for roles demanding higher physical output. This outlines the complexity when establishing normative data for sailing in general.

The physical and physiological characteristics reported in the present study also varied when compared to other sailing studies. $\dot{V}O_{2max}$ of our present study (53.4 ± 8.5 $ml.mn^{-1}.kg^{-1}$), seems to be (i) lower than in elite laser sailors (58.2 ± 4.7 $ml.mn^{-1}.kg^{-1}$; Castagna and Brisswalter, 2006), (ii) higher than finn sailors (47.6 ± 3.5 $ml.mn^{-1}.kg^{-1}$; Bojsen-Moller et al., 2007) and (iii) similar to America's Cup grinders (52.2 ± 4.6 $ml.mn^{-1}.kg^{-1}$; Bernardi et al., 2007). The differences outlined in these studies could be related to the effect induced by the various peculiar onboard activity and/or the use of various testing methodologies. Nevertheless, research has outlined the low aerobic demands during a dinghy regatta (Portier et al., 2003). Indeed, sailors participating on TDF engage in high intensity hoisting and trimming actions when maneuvering. Between the different maneuvers, the sailors are involved in quasi-isometric hiking. Previous studies showed a significantly decreased oxygenation pattern in the m. Vastus Lateralis during hiking (inherent to isometric contractions > 30% maximal voluntary contraction), indicating an imbalance between oxygen supply and demand, and probably due to restricted muscle blood flow (Bourgois et al., 2016). The sailors undertaking the MRWT-MPO test in this study (565.9 ± 97.9 W) held similar anaerobic capacity than highly trained college level rowers (548.97 ± 95.57 W; Shaharudin and Zanotto, 2014). This comforts our understanding that TDF sailors rely significantly on anaerobic energy delivery during racing.

Lower body power was assessed using SJ and CMJ protocols. Few other studies have analyzed such parameters on sailors. Indeed, only one has assessed national level sailors for lower body power (Tan et al., 2006) and found similar results to the present study (36.0 ± 6.2 vs 34.0 ± 4.0 cm) on the SJ. Nevertheless, it seems that no correlation between jumping performance and hiking potential exists (Tan et al., 2006). Hiking is characterized by strong isometric contractions and coactivation of the muscles involved: quadriceps, hamstrings, abdominal and paravertebral muscles (Larsson et al., 1996; Tan et al., 2006). Numerous studies have analyzed isokinetic muscle strength of knee, hip and trunk flexors and extensors of elite level sailors (Aagaard et al., 1998; Chicoy and Encarnacion-Martinez, 2015). These studies have highlighted the high demands of these specific strengths on hiking performance. In the present study, to assess maximal isometric strength of the lower body, an IMTP test was performed. To date, this is the first study to use such a protocol in an elite sailing environment. Relative strength should be considered when assessing sailors, or other sports, where body weight is regulated by competition rules. Isometric maximal voluntary force, using the IMTP test, has been linked to functional performance in sport (Ran-Wang et al. 2016). We aimed at analyzing isometric strength at hip/knee angles like those of other sailing studies (Chicoy and Encarnacion-Martinez, 2015) by using the IMTP. Interestingly, maximal IMTP discriminated between SA and LSA when the results were compared relatively to bodyweight ($IMTP_W$). $IMTP_W$ performance was significantly correlated ($r=0.41$; $p<0.01$) with rank on NS courses. These results suggest that a high level of relative strength is necessary in TDF sailors, and supports the findings in other studies analyzing the relationship between lower body strength and sailing performance (Blackburn and Hubinger, 1995).

Trimming and hoisting actions requires powerful and energetic movements on the sheets (Bay and Larsson, 2013). By doing so, sailors increase the amount of apparent wind that covers the sail and, thus, increase boat speed. Indeed, it was thought that sailors participating in the TDF would have high amounts of maximal strength due to the predominance of pulling actions necessary when maneuvering the boat. Differences can be outlined for the one repetition maximum between Americas Cup sailors (99.41 ± 5.4 kg; Pearson et al., 2009) and TDF sailors of this present study (77.5 ± 13.0 kg). Nevertheless, it should be noted that the America's cup sailors were heavier (97.8 ± 12.5 vs 74.8 ± 6.6 kg). Bar velocity at fixed loads was also evaluated and turned out to be significantly different between SA and LSA at 20 kg loads. Neville and collaborators (2009) reported that successful boats maneuvered faster than less successful boats. Faster bar velocity at submaximal loads could be directly correlated to hoisting/trimming efficiency and, thus, sailing performance through faster maneuvers. BP_{mpv20} was in fact significantly correlated to racing outcome (NS and CR) and TDF final ranking ($r=.80$; $p<0.05$). Future research should therefore aim at establishing associations between bar velocities at fixed loads with hoisting actions.

Handgrip strength has received a considerable amount of interest in past research. Indeed, it has been linked to performance in many sports (Cronin et al., 2017). Significant decreases in grip strength between pre- and post-sailing training sessions have been reported in junior male semi-elite sailors (Bateup et al., 2016). The TDF sailors (61.1± 9.5 kg) reported stronger HGS_{Dom} than collegiate dinghy sailors (48.28 ± 5.31 kg; Pulur, 2011). These results outline the high mechanical stress placed on forearms when maneuvering TDF boats. HGS_{Dom} was found to significantly discriminate between SA and LSA. It was also correlated to racing outcome (NS and CR). These results could indicate more efficiency to maneuver the D24 at higher speeds (i.e. optimized gripping ease against high resistance in sheets and cranks). It would seem interesting to analyze the acute and chronic load effects of sailing on handgrip strength.

An interesting finding of this study was that no significant difference was found between crew positions for physical and physiological parameters. This could indicate an equal importance of overall fitness of TDF sailors to maneuver the boat. Indeed, it was not rare to see sailors switch position when racing or during specific maneuvers throughout the TDF. Comparison of physical and physiological parameters from 21 elite sailors indicated that SA had greater strength (HGS_{Dom}), muscular voluntary contraction ($IMTP_{W}$) and power (BP_{mpv20}) compared to LSA. Differences were most marked between trimmers ($IMTP_{W}$, BP_{mpv20}, BP_{mpv30} and BP_{mpv40}) and bowmen (BP_{mpv20}) which are primarily responsible for trimming and material handling (sails, ropes and cranks). A possible explanation highlighting the difference in HGS_{Dom} found in this study could result from higher training loads on-water and off- of SA (Bateup et al., 2016).

Study limitations

Some limitations in the present study have been identified during the analysis process. First, the sample size of 21 elite level sailors accounted for 6 fully crewed boats out of 23. Testing more crew members may have permitted to perform more significant correlational analysis between crew characteristics, as a mean or sum, and ranking. Second, as previously mentioned, sailing relies on bio-informational and strategic qualities to perform. Indeed, overall and specific sailing experience was not accounted for and could have influenced performance and account for discrimination of success.

Conclusion

Overall, the findings have identified multiple variables (technical and physical) that discriminate between successful and less successful athletes/boats. The results can be used as normative data to compare, detect and guide athletes in their preparation for performance. The present study highlights successful sailors having stronger grip strength, more powerful bench-pull and higher IMTP than their less successful counterparts. Successful boats displayed a faster average speed, maximal speed and more efficient starting performance. Nevertheless, these findings should be applied with caution to other populations (i.e. youths, less experimented sailors and other sailing categories).

Practical applications

This study may provide useful information to coaches, sports scientists and sailors in the planning and implementation of physical and technical training interventions. Where practitioners wish to evaluate and provide sailors with reliable training interventions the use of handgrip strength, submaximal pulling velocity and isometric mid-thigh pull testing protocols are suitable. We believe that future studies should focus on two particular aspects: (1) identifying the effects of internal and external training load on technical and physical performance indicators during the preparation and competitive phase of the TDF and (2) examining sailors' experience (e.g., vessel, position, training load) in order to identify potential performance and/or talent pathways.

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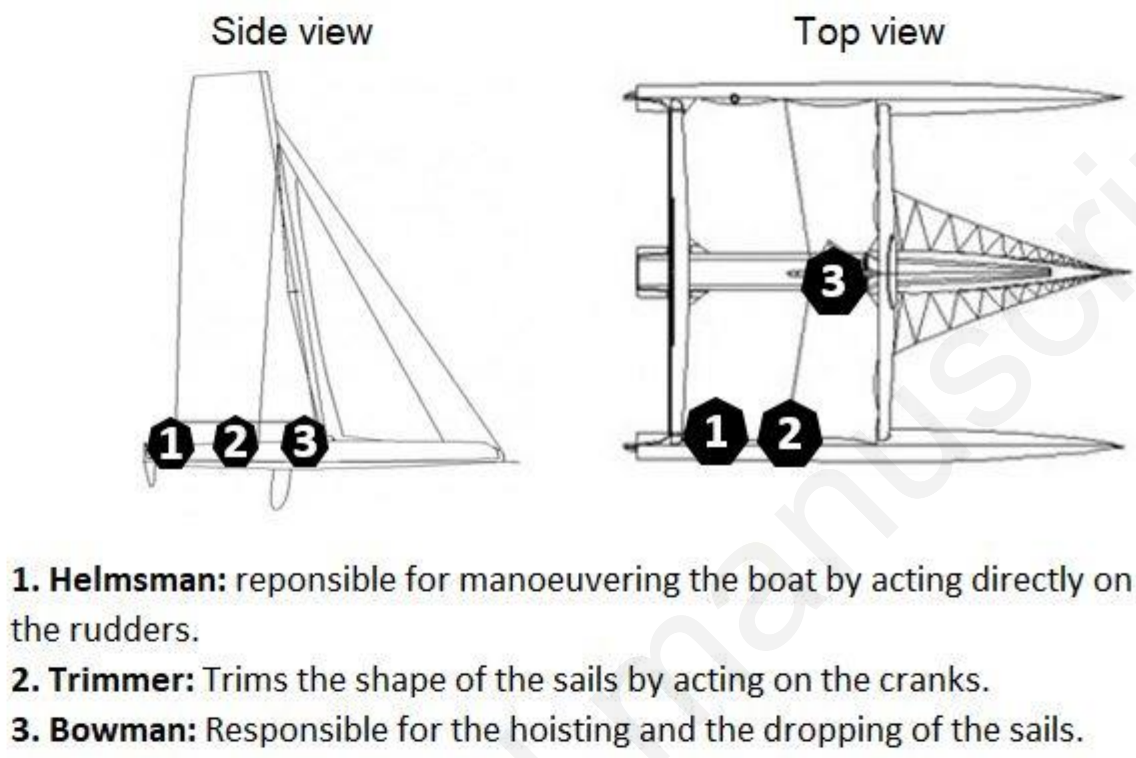

Figure 1. Side and top view of a DIAM24 One Design multihull. The figure shows the position and roles of the 3 athletes on-board. In winds over 10 knots all three sailors are hiking on the same hull.

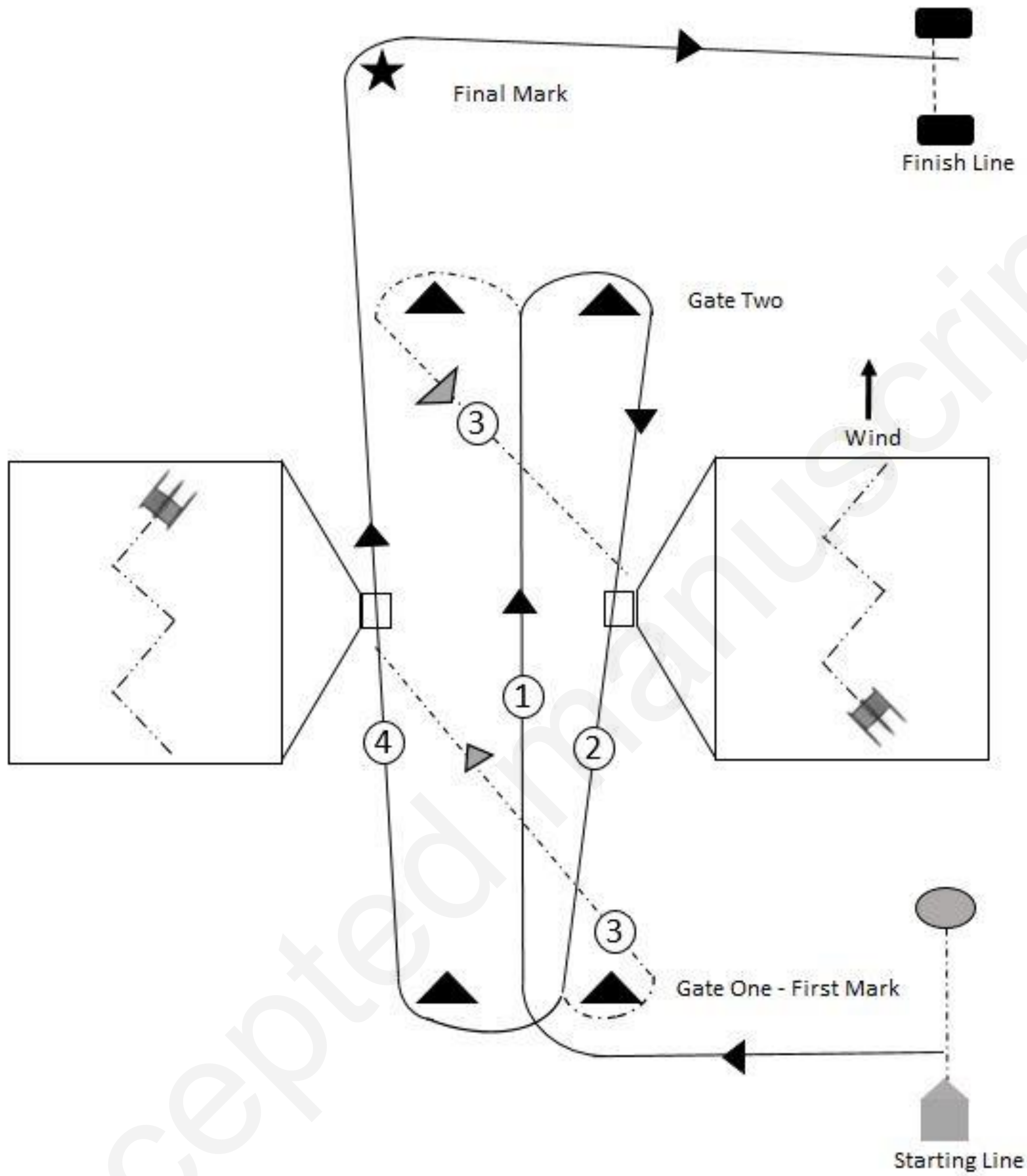

Figure 2. A typical Tour de France nautical stadium course. (1) Represents the downwind portion and (2) the upwind portion. (1) And (2) can be sailed up to three times according to race committee. Teams must go through the gates and can chose to round either mark (3). (4) Represents the final straight before gybing towards the finish line.

Table 1. Differences in sailing parameters between successful boats and less successful boats.

	All boats (n=23)		Successful Boats (n=7)		Less successful boats (n=16)	
	Mean (SD)	[Range]	Mean (SD)	[Range]	Mean (SD)	[Range]
Nautical Stadium						
Sailing distance (m)	4168.5 (76.2)	[4014.8-4318.7]	4131.9 (65.3)	[4048.5-4235.5]	4175.8 (82.7)	[4014.8-4318.7]
Average speed ($m.s^{-1}$)	4.1 (0.2)	[3.8-4.4]	4.2 (0.1)	[4.1-4.4]	4.0 (0.1)**	[3.8-4.3]
Maximal speed ($m.s^{-1}$)	7.3 (0.2)	[7.0-7.6]	7.5 (0.1)	[7.3-7.6]	7.2 (0.1)**	[7.0-7.5]
Course coverage (%)	158.5 (3.0)	[152.74-164.6]	157.4 (2.0)	[155.0-160.5]	159.0 (3.3)	[152.4-164.6]
Total Maneuvers	8.6 (0.9)	[6.8-10.3]	8.9 (0.8)	[7.9-10.3]	8.5 (0.9)	[6.7-10.0]
Tacks	3.8 (0.6)	[2.7-5.0]	4.1 (0.4)	[3.6-4.5]	3.7 (0.7)	[2.7-5.0]
Gybes	4.8 (0.6)	[3.7-6.0]	4.9 (0.5)	[4.2-5.7]	4.8 (0.7)	[3.7-6.0]
Start (rank)	5.9 (1.5)	[3.5-9.3]	4.8 (0.9)	[3.5-5.9]	6.6 (1.3)**	[4.8-9.3]
Start (s)	25.4 (8.2)	[12.2-44.9]	18.8 (4.0)	[12.2-22.8]	28.5 (7.7)**	[18.2-44.9]
Coastal Raid						
Sailing distance (m)	78500 (3500)	[69600-82500]	78600 (3200)	[71200-81700]	78500 (3600)	[69600-82500]
Average speed ($m.s^{-1}$)	5.4 (0.3)	[4.7-5.7]	5.5 (0.3)	[4.9-5.7]	5.3 (0.2)*	[4.7-5.5]
Maximal speed ($m.s^{-1}$)	9.1 (0.4)	[8.1-10.3]	9.3 (0.4)	[8.8-10.3]	9.0 (0.3)**	[8.1-9.3]
Course coverage (%)	134.0 (4.8)	[118.0-139.5]	134.4 (2.4)	[130.0-138.2]	133.6 (5.7)	[118.0-139.5]
Total Maneuvers	23.9 (1.3)	[20.4-25.8]	24.0 (1.8)	[20.4-25.8]	23.8 (1.0)	[22.2-25.8]
Tacks	11.6 (1.2)	[9.4-13.8]	12.1 (1.1)	[10.2-13.8]	11.5 (1.3)	[9.4-13.6]
Gybes	12.2 (1.0)	[10.2-13.6]	12.0 (1.1)	[10.2-13.6]	12.4 (1.0)	[10.6-13.6]
Start (rank)	11.7 (4.3)	[5.0-20.0]	9.1 (2.3)	[5.0-12.0]	12.9 (4.4)*	[7.0-20.0]
Start (s)	219.1 (103.1)	[71.6-479.8]	162.2 (65.0)	[71.6-236.2]	245.6 (107.1)*	[108.0-479.8]

* Significant difference with values of successful boats; P ≤ 0.05.
** Significant difference with values of successful boats; P ≤ 0.01.

Table 2. Age and anthropometric characteristics (mean (SD)) of TDF sailors.

	n	TDF (campaigns)	Age (years)	Weight (kg)	Height (cm)	Sitting Height (cm)	Arm Span (cm)	BMI (kg.m⁻²)	∑3 Skinfold (mm)	Body Fat (%)	LBM (kg)	Girth Arm (cm)	Girth Thigh (cm)	Girth Calves (cm)
Successful														
Helmsmen	4	2.8 (0.5)	22.0 (1.4)	70.9 (5.9)	176.4 (9.4)	93.1 (4.6)	181.3 (7.5)	22.8 (1.2)	29.6 (11.0)	13.2 (3.8)	61.5 (5.3)	30.4 (1.8)	53.0 (1.6)	34.8 (1.6)
Bowmen	3	2.7 (0.6)	22.3 (2.1)	71.8 (6.1)	175.5 (5.3)	91.0 (2.6)	190.0 (2.1)	23.3 (0.6)	22.0 (4.4)	10.7 (1.7)	64.1 (4.3)	30.8 (2.0)	54.3 (0.9)	36.0 (0.9)
Trimmers	3	3.0 (0.0)	23.7 (1.2)	77.8 (4.2)	183.3 (6.0)	95.7 (3.3)	188.3 (10.4)	23.1 (0.6)	26.0 (15.4)	12.0 (5.2)	68.4 (5.0)	32.7 (1.3)	55.3 (1.8)	34.5 (1.8)
All	10	2.8 (0.4)	22.6 (1.6)	73.3 (5.8)	178.2 (7.5)	93.3 (3.8)	185.8 (7.7)	23.0 (0.8)	26.3 (10.4)	12.1 (3.6)	64.4 (5.3)	31.2 (1.8)	54.1 (1.3)	35.1 (1.5)
Less-Successful														
Helmsmen	3	2.7 (1.2)	23.7 (4.5)	68.4 (3.9)	176.4 (14.2)	92.3 (4.6)	186.0 (12.5)	21.4 (2.3)	29.1 (8.0)	13.2 (2.6)	59.4 (3.8)	29.1 (1.4)	52.2 (3.2)	33.8 (1.3)
Bowmen	4	2.7 (1.3)	25.0 (5.9)	79.1 (8.0)	175.5 (1.9)	92.9 (1.6)	183.8 (4.2)	24.3 (2.3)	20.1 (4.6)	10.1 (1.6)	71.0 (6.5)	32.3 (4.0)	53.1 (7.0)	39.8 (6.2)
Trimmers	4	3.0 (0.0)	25.8 (6.9)	79.1 (3.8)	183.3 (6.2)	91.4 (4.3)	184.3 (3.8)	24.2 (1.9)	42.0 (13.5)	17.5 (4.5)	65.1 (3.6)	31.1 (2.6)	55.4 (1.3)	35.9 (1.4)
All	11	2.7 (0.4)	24.9 (5.5)	73.5 (7.6)	180.4 (7.3)	92.2 (3.4)	184.6 (6.5)	23.5 (2.4)	30.5 (13.1)	13.65 (4.0)	65.7 (6.5)	31.0 (3.0)	53.7 (4.4)	36.7 (4.4)
Total														
All	21	2.8 (0.9)	23.8 (4.2)	74.8 (6.6)	179.3 (7.3)	92.7 (3.5)	185.1 (6.9)	23.3 (1.8)	28.5 (11.8)	12.91 (4.0)	65.0 (5.9)	31.1 (2.5)	53.9 (3.2)	35.9 (3.3)
Range		[1-4]	[17-33]	[65.5-88.8]	[163.5-190.5]	[85.5-100]	[173.5-200]	[19.3-26.8]	[13-54.5]	[7.6-22]	[55.3 - 78.9]	[27.5 -37]	[44.5-61.5]	[32.5-41]

TDF: Tour de France; BMI: Body Mass Index; LBM: Lean Body Mass; Note: Successful, sailors finishing in the top 7 teams; Less successful, sailors finishing 8th to 23rd.
* Significant difference with values of successful athletes; P ≤ 0.05 (**; P ≤0.01).
† Significant difference with values of successful athletes at same position; P ≤ 0.05 (††; P ≤ 0.01)

Table 3. Physical and physiological characteristics (mean (SD)) of TDF sailors.

	n	HGS_{Dom} (kg)	HGS_{Sum} (kg)	SJ_H (cm)	CMJ_H (cm)	IMTP (N)	$IMTP_W$ ($N.kg^{-1}$)	MRWT-MPO (W)	BP_{1RM} (kg)	BP_{MPV20} ($m.s^{-1}$)	BP_{MPV30} ($m.s^{-1}$)	BP_{MPV40} ($m.s^{-1}$)	BP_{MPV50} ($m.s^{-1}$)	$\dot{V}O_{2max}$ ($ml.mn^{-1}.kg^{-1}$)
Successful														
Helmsmen	4	59.3 (5.6)	113.5 (9.7)	32.7 (4.8)	37.6 (5.2)	2649.9 (397.6)	37.3 (3.4)	501.3 (82.3)	73.8 (6.3)	1.5 (0.02)	1.2 (0.1)	1.1 (0.1)	0.9 (0.1)	53.5 (6.4)
Bowmen	3	72.0 (6.9)	138.0 (11.1)	42.8 (5.5)	37.6 (2.2)	2894.1 (189.7)	40.4 (1.1)	623.7 (115.0)	83.3 (2.9)	1.7 (0.1)	1.4 (0.1)	1.2 (0.2)	1.0 (0.1)	52.5 (14.0)
Trimmers	3	66.3 (8.5)	127.3 (20.1)	35.6 (1.0)	39.0 (2.4)	2955.6 (144.9)	38.0 (2.2)	632.7 (126.0)	81.7 (10.4)	1.7 (0.1)	1.5 (0.1)	1.3 (0.1)	1.2 (0.1)	56.5 (2.2)
All	10	65.2 (8.3)	125.0 (16.3)	35.6 (1.0)	37.9 (38.6)	2814.9 (293.5)	38.4 (2.7)	577.4 (114.2)	79.0 (7.8)	1.6 (0.1)	1.3 (0.1)	1.2 (0.2)	1.0 (0.1)	54.1 (7.8)
Less-Successful														
Helmsmen	3	56.3 (15.4)	110.3 (27.5)	39.3 (7.7)	36.5 (4.7)	2433.4 (776.7)	35.2 (9.8)	488.7 (46.0)	67.5 (4.3)	1.3 (0.2)	1.1 (0.0)	1.0 (0.06)	0.8 (0.06)	48.7 (13.6)
Bowmen	4	58.3 (9.9)	114.3 (18.9)	36.8 (5.8)	38.7 (7.5)	2723.2 (614.7)	34.3 (5.7)	586.0 (109.4)	88.8 (20.15)	1.5 (0.1)†	1.4 (0.2)	1.2 (0.2)	1.0 (0.2)	57.3 (13.6)
Trimmers	4	57.3 (5.9)	110.8 (11.8)	31.0 (5.6)	35.8 (6.8)	2527.7 (377.5)	31.9 (3.4)†	575.0 (66.4)	70.0 (13.5)	1.3 (0.1)††	1.2 (0.1)††	1.1 (0.1)†	0.9 (0.3)	51.4 (6.8)
All	11	57.4 (9.4)*	111.9 (17.5)	35.4 (6.7)	37.1 (6.1)	2573.1 (540.8)	33.7 (5.9)*	555.5 (84.9)	76.1 (16.8)	1.3 (0.2)**	1.2 (0.2)	1.1 (0.1)	0.9 (0.2)	52.8 (9.4)
Total														
All		61.1 (9.5)	118.1 (17.8)	36.0 (6.2)	38.6 (5.6)	2688.2 (447.5)	35.9 (5.1)	565.9 (97.9)	77.5 (13.0)	1.5 (0.2)	1.3 (0.2)	1.1 (0.2)	1.0 (0.2)	53.4 (8.5)
Range		[46-80]	[90-150]	[24.1-49.1]	[26.2-46.7]	[1567.5-3160]	[24.5-43.7]	[430-774]	[50-105]	[1.04-1.83]	[1.06-1.63]	[0.92-1.45]	[0.77-1.29]	[36.5-76.8]

HGS_{Dom}: Dominant Hand Grip Strength; HGS_{Sum}: Sum of Hand Grip Strength; SJ_H: Squat Jump Height; SJ_{PP}: Squat Jump Peak Power; CMJ_H: Countermovement Jump Height; CMJ_{PP}: Countermovement Jump Peak Power; IMTP: Isometric Mid-Thigh Pull; $IMTP_W$: Isometric Mid-Thigh Pull relative to Weight; MRWT-MPO: Modified Rowing Wingate Test Mean Power Output; BP_{1RM}: Bench Press 1RM; BP_{MPV20}: Bench Press Velocity at 20 kg; BP_{MPV30}: Bench Press Velocity at 30 kg; BP_{MPV40}: Bench Press Velocity at 40 kg; BP_{MPV50}: Bench Press Velocity at 50 kg; $\dot{V}O_{2max}$: Maximal Oxygen Uptake. Note: Successful, sailors finishing in the top 7 teams; Less successful, sailors finishing 8th to 23rd;
* Significant difference with values of successful athletes; P ≤ 0.05 (**; P ≤0.01).
† Significant difference with values of successful athletes at same position; P ≤ 0.05 (††; P ≤ 0.01)

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