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HAL Authorization

Key Performance Indicators in Tour de France Sailing.

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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 \pm SD; age = 23.81 \pm 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.

60 Introduction

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

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

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

88 Sport performance requires the optimal exploitation of the athletes' potential, but little is
89 known about the contribution of different factors (i.e. physiological, psychological,
90 technical and tactical/strategic) in sailing performance. To date, it was mainly reported

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4 91 that sailing is a sport for which bio-informational and strategic qualities are fundamental
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6 92 (Araújo et al., 2015). Although the anthropometric, physical and physiological
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8 93 characteristics are essential to performance in most sports, their influence on sailing
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10 94 performance still remains to be analyzed. Establishing normative data, by engaging in
11
12 95 profiling approaches, would be a valuable mean to understanding the needs for optimizing
13
14 96 sport specific performance. Such data would be promoting a better understanding for
15
16 97 identifying talent (Roczniok et al., 2013), determining an athlete's strengths and
17
18 98 weaknesses (Duthie, 2006), guiding tactical choices (Fernandez-Fernandez et al., 2009)
19
20 99 and elaborating sport-specific strength and conditioning programs. Therefore, the purpose
21
22 100 of this study was to: (1) document the nature and technical key performance indicators of
23
24 101 the TDF; (2) provide insights into the anthropometric, physical and physiological
25
26 102 characteristics of elite inshore sailors. We hypothesized that sailing performance factors
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28 103 (e.g., distance covered at different sailing speeds) and anthropophysiological
29
30 104 characteristics would be identified and contribute to racing success and ranking.
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34 107 **Materials and methods**

35 108 **Subjects**

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38 109 Professional male international inshore sailors (N = 21; mean \pm SD; age = 23.81 ± 4.18
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40 110 years; height = 179.32 ± 7.30 cm; body mass = 74.78 ± 6.56 kg) were assessed in the
41
42 111 final preparation phase leading up to the 2019 TDF. Subjects were informed of the testing
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44 112 procedures, potential risks and the purpose of their participation. All subjects had already
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46 113 competed in international competitions. Their collective experience included 59 TDF
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48 114 campaigns. At the time of testing, the subjects had completed 6 months of sailing training
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50 115 and had been actively participating in strength and conditioning programs for at least three
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52 116 years. None of the participants reported injuries or diseases that would impair their
53
54 117 physical performance. The study protocol was approved by the ethics committee of
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56 118 Rennes University. Written informed consent was obtained from all participants before the
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58 119 start of the study. In this study, criteria used to qualify an athlete's performance was based
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60 120 on the team's final ranking. An athlete was categorized as "successful" (SA, n=10) if he
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121 crewed a successful boat (SB). Less successful athletes (LSA, n=11) crewed a less
122 successful boat (LSB).

123 **Procedures**

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

136 **Regatta analysis**

137 The 42nd sailing Tour de France took place in July 2019 and was held in 7 French coastal
138 cities. This edition was disputed between 23 international teams over 17 days (10 NS and
139 5 CR) interspersed by two days of recovery. This resulted in 99 races (84 qualifying heats,
140 10 finals and 5 CR). Points were attributed daily according to results (i.e.: 1st receives 50
141 points, 2nd receives 49... last receives 28) and were accumulated throughout the
142 competition. The final ranking established the winner of the TDF.

143 Race data – including sailing distance (m), average speed (m.s⁻¹), maximal speed (m.s-
144 ¹), course coverage (%) (i.e., distance sailed / course distance), start performance (rank
145 and time gap at the first mark) and maneuvers (tack and gybe; count) – were collected
146 during all 84 qualifying heats and 5CR. GPS units (Mylaps® X5 Global Positioning
147 System; 9-channel GPS receiver; location measurement accuracy 2.5 m; dimensions 109
148 × 59 × 22 mm; weight 95 g; temperature range –20 – +55°C) were placed on all of the 23
149 boats. A boat was categorized as “successful” (SB, n=7) if it qualified for more than half

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150 of the daily finals. Less successful boats (LSB, n=16) qualified for half or less of the daily
151 finals.

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153 **Anthropometric, physical and physiological assessment**

154 *Session 1: Anthropometric measurement.*

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

170 *Session 2: Physical testing.*

171 Physical and physiological characteristics were measured in randomized order.

172 Handgrip strength. Maximal isometric hand-grip strength (HGS) was assessed with a
173 Jamar® handgrip dynamometer (Sammons Preston Corp., Bolingbrook, Ill., USA). The
174 test positions were standardized (Svantesson et al., 2009). Three trials were performed
175 on each hand. The first three trials started with the right hand. Subjects were instructed to
176 squeeze the device as hard as possible for 3 s. The time between each trial was 15 s and
177 3 min of rest was allowed when changing hands. The maximal measure of the three trials

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4 178 was retained in kilograms (Kg). Sum (HGS_{sum}) of both hands and dominant hand (HGS_{dom})
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6 179 measures were assessed and included in the results.
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9 180 Vertical jumps. Lower body power was tested on the squat jump (SJ) and
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11 181 countermovement jump (CMJ) using a chronojump contact mat (Chronojump-
12
13 182 Boscosystem™, Software, Spain). Each subject had three attempts per jump with 1 min
14
15 183 of rest between trials. Subjects started with SJ and, after a 3 min passive recovery, were
16
17 184 assessed on CMJ. Instructions for the jumps were explained and controlled with a
18
19 185 goniometer for the SJ. Subjects were instructed to descend to 90° knee flexion. Once
20
21 186 position was reached, a countdown of “3, 2, 1, jump” was indicated orally. A validated and
22
23 187 reliable smartphone application (Balsalobre-Fernandez et al., 2015) was used for lateral
24
25 188 video analysis. This allowed to track lateral kinematics and thus avoid collecting results
26
27 189 that involved a countermovement action. Both the SJ and CMJ were done with subjects
28
29 190 placing hands on their hips as to avoid arm movement. For the CMJ, athletes were
30
31 191 instructed to perform a rapid eccentric phase, immediately followed by a rapid concentric
32
33 192 phase with the intention to jump as high as possible. Height and peak power of the best
34
35 193 SJ (SJ_H and SJ_{PP}) and CMJ (CMJ_H and CMJ_{PP}) performances were reported for analysis.
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37 194 Isometric mid-thigh pull. Testing for isometric mid-thigh pull (IMTP) was conducted on a
38
39 195 customized pulling rack apparatus specifically developed for data collection. IMTP was
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41 196 performed using two portable force platforms sampling at 1000 Hz (Pasco™, Rosedale,
42
43 197 USA) and previously validated (Peterson Silveira et al., 2017). The force plates were
44
45 198 connected to a portable laptop running the Capstone Software Program (Pasco™,
46
47 199 Rosedale, USA). Knee angle was measured with a goniometer, to ensure a range of 125-
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49 200 140° (Haff et al., 2013). The bar height was adjusted to meet the testing criteria and to
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51 201 accommodate to the athlete’s size. Once the test had been thoroughly described and
52
53 202 testing parameters were set, a specific warm-up was conducted. Athletes were provided
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55 203 with two warm-up pulls, 1 at 50 % and 1 at 75 % of perceived maximum effort, separated
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57 204 by 1 min of rest. Once body position was stabilized (verified by observation and live force
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59 205 measures), the subject was given a countdown of “3, 2, 1, pull.” Minimal pre-tension was
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61 206 allowed to ensure that there was no slack in the subject’s body before initiation of the pull.
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63 207 Athletes performed 3 maximal IMTP with the instruction to pull the bar with maximal effort
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4 208 as quickly as possible and push the feet down into the force platform. The time between
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6 209 each trial was 1 min. Each maximal isometric trial was performed for 5 s. The best trial
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8 210 was used for data collection and was analyzed relatively to the athlete's body weight
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10 211 (IMTP_w).

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12 212 Force-velocity pulling profile. Force-velocity curve testing on the bench-pull (BP) was
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14 213 conducted on an elevated bench-pull device placed above a guided squat rack (Smith
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16 214 machine). The Smith machine (Technogym®, Cesena, Italy) allowed for vertical
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18 215 displacement through guided rods. A Chronojump linear position transducer
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20 216 (Chronojump™, Barcelona, Spain) was placed below the bar and automatically calculated
21
22 217 the kinematic parameters of every repetition. Subjects were instructed to pull the bar with
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24 218 maximum effort until the barbell hit the bench 8 cm below the subject's chest. The barbell
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26 219 was then lowered and a brief pause of 1 s was observed to avoid the rebound effect or
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28 220 any stretch-shortening cycle interference. The protocol followed Sanchez-Medina's
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30 221 instructions (Sanchez-Medina et al., 2014). Initial load started at 20 kg and increased by
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32 222 increments of 10 kg until mean propulsive velocity (BP_{MPV}) was lower than 0.7 m.s⁻¹. Three
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34 223 attempts were executed for light (< 50 % 1RM), 2 for medium (50–80 % 1RM) and only 1
35
36 224 for the heaviest (> 80 % 1RM) loads. Inter-set rest intervals were 3 min for the light and
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38 225 medium loads and 5 min for the heaviest loads. The fastest bar speed for each load was
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40 226 recorded. The maximum load that could be lifted once was considered the athlete's 1RM
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42 227 (BP_{1RM}). BP_{MPV} was calculated for the loads that were completed by all subjects (BP_{MPV20},
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44 228 BP_{MPV30}, BP_{MPV40} and BP_{MPV50}).

45 229 Anaerobic capacity. Anaerobic capacity was tested using a modified rowing Wingate test
46
47 230 (MRWT) on a rowing ergometer Concept II-D (Concept 2 INC™, Vermont, USA). The
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49 231 flywheel was set at 130 drag factor. Subjects were allowed 3 min of warm-up at a rate of
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51 232 perceived exertion of 5 out of 10. Athletes then completed the 30 s all-out test. Exercise
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53 233 performance was expressed as mean power output (MPO) in watts (W) and was
54
55 234 calculated automatically by Concept II-D. The procedure has been described previously
56
57 235 (Riechman et al., 2002).

58
59 236 Maximal oxygen uptake. Maximal oxygen uptake ($\dot{V}O_{2max}$) was assessed through a step
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61 237 incremental test (MOU_{T25}) on an electromagnetically braked cycle ergometer (Kettler®
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4 238 Ense-Parsit, Germany). $\dot{V}O_{2max}$, expressed as $ml.min^{-1}.kg^{-1}$, measures were collected
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6 239 through the use of a portable self-contained metabolic cart CardioCoach (Korr Medical
7
8 240 Technologies®, Salt Lake City, UT) and previously validated (Dieli-Conwright et al, 2009).
9
10 241 Subjects were given time to adjust seat and bar height before starting the test. MOU_{T25}
11
12 242 started at 20 W and increased by $25 W.min^{-1}$ until voluntary exhaustion (Amann et al.,
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14 243 2004). A cadence of 90-100 RPM was standardized throughout the test. During the
15
16 244 MOU_{T25} the following variables were constantly registered: heart rate (HR), minute
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18 245 ventilation (\dot{V}_E) and oxygen uptake ($\dot{V}O_2$). Prior to each test, the gas analyzer was
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20 246 calibrated according to the manufacturer's specifications. $\dot{V}O_{2max}$ was determined when
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22 247 physical signs suggestive of exhaustion were apparent and at least one of the following
23
24 248 two criteria were met; (1) HR_{max} was no less than 15 beats below the predicted maximum
25
26 249 [$220 - (0.65 \times age)$; Spiro 1977] and (2) a steady state of $\dot{V}O_2$ despite an increase in
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28 250 workload (Vehrs et al., 2007).

29 **Statistics**

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31 252 Data was calculated through standard statistical methods and are presented as mean \pm
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33 253 standard deviation. All variables were considered normally distributed through analysis
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35 254 with the Shapiro-Wilk test, histograms and skewness values prior to analysis. One-way
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37 255 analysis of variance (ANOVA) was used to compare anthropometric, physiological and
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39 256 physical measures for the different crew positions. Independent t-tests were performed to
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41 257 determine if significant differences existed between physical profiles (SA vs. LSA) and
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43 258 technical parameters (SB vs. LSB). When results were significantly different, an effect size
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45 259 (ES) calculation was used. ES was evaluated using Cohen's d along with 95% confidence
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47 260 intervals. ES of ≤ 0.2 , 0.21-0.60, 0.61-1.20, 1.21-2.0, ≥ 2.0 were considered as trivial, small,
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49 261 moderate, large and very large, respectively (Batterham and Hopkins 2006). Finally,
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51 262 Spearman's Rank Order Correlation (r) was used to identify the relationship between
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53 263 outcome (race and overall standings) and the key performance indicators identified as
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55 264 significant in the independent t-tests. Statistical analyses were performed using the SPSS
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57 265 package (15.0 version; SPSS, Inc., Chicago, IL, USA). The level of significance was set
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59 266 at $p < 0.05$.

60 **Results**

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4 268 *Regatta analysis*

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7 269 Mean race duration was 17 ± 2 min for NS and 244 ± 35 min for CR. Course distance was
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9 270 2672.9 ± 610.3 m for NS and 59000 ± 17500 m for CR. Teams participated between 47
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11 271 and 57 races and accumulated 474.3 ± 38.3 maneuvers (NS: 355.1 ± 37.8 ; CR: $119.1 \pm$
12
13 272 6.6). Gybes (downwind maneuver; lasted ~ 12 s) were more recurrent than tacks (upwind
14
15 273 maneuver; lasted ~ 8 s), respectively 259.3 ± 26.8 vs. 214.9 ± 26.1 . Maneuver count per
16
17 274 NS heat was 8.7 ± 0.9 and 23.8 ± 1.3 for CR. Sailing distance for NS heats was $4161.8 \pm$
18
19 275 80.1 m and 78500 ± 34900 m for CR. Course coverage for NS was 158.5 ± 3.0 % and
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21 276 133.8 ± 4.9 % for CR.

22 277 *Technical key performance indicators*

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24
25 278 Sailing parameters collected during the TDF are analyzed in Table 1 for SB, LSB and all
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27 279 boats. Race outcome for NS was significantly correlated ($p < 0.01$) with starting
28
29 280 performance ($r = .52$), maximal speed ($r = .33$) and average speed ($r = .76$). Coastal raid
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31 281 ranking was correlated ($p < 0.01$) with starting performance ($r = .58$), maximal speed ($r = .43$)
32
33 282 and average speed ($r = 0.81$). All three of the highlighted performance parameters were
34
35 283 also significantly correlated to final rankings of the TDF.

36 284 *Profiling and physical key performance indicators*

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38
39 285 Table 2 shows mean (\pm SD) for the age and anthropometric characteristics of professional
40
41 286 male TDF sailors. No significant differences were observed in anthropometric parameters
42
43 287 between crew positions (Table 2) and success attribute. The physical and physiological
44
45 288 profiles of sailors are reported in Table 3. Successful sailors had stronger HGS_{Dom}
46
47 289 ($ES = 0.82$) and $IMTP_W$ relatively to body weight ($ES = 0.93$) and exerted faster BP_{MPV20}
48
49 290 ($ES = 1.18$) than their less successful counterparts. The differences between SA and LSA
50
51 291 were significant ($p = 0.001$). HGS_{Dom} ($r = 0.54$), $IMTP_W$ ($r = 0.41$) and BP_{MPV20} ($r = 0.61$) were
52
53 292 significantly correlated ($p < 0.01$) to rank in NS heats. CR results were correlated to HGS_{Dom}
54
55 293 ($r = 0.37$; $p < 0.05$) and BP_{MPV20} ($r = 0.74$; $p < 0.01$). BP_{MPV20} showed strong correlation with
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57 294 final TDF rankings ($r = 0.8$; $p < 0.05$).

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60 296 **Discussion**

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4 297 The aim of this present study was threefold. First, our objective was to analyze and
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6 298 report the nature of sailing during the TDF. Second, we attempted to identify the key
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8 299 performance indicators associated with racing outcome. Third, we directed a descriptive
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10 300 analysis of anthropometric, physical and physiological profiles of elite level sailors
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12 301 participating in the TDF. Most prominently, the analysis has indicated the capacity to
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14 302 discriminate between SB/LSB and SA/LSA by considering technical and physical
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16 303 parameters.

17 304 18 19 305 *Regatta analysis*

20
21 306 This is the first report on the nature of sailing during the TDF. Overall, sailors travelled
22
23 307 541300 ± 64900 m in 1792.3 ± 409.3 min during the 15 days of competition. Mean race
24
25 308 duration (SN: 17 min; CR: 244 min) and the number of maneuvers were highly variable
26
27 309 due to external parameters (e.g. race course and tactics, environmental condition).
28
29 310 Insights on the nature of energetic demands and work to rest ratio can nevertheless be
30
31 311 estimated. In sailing, particularly where sailors must hike, work to rest ratio should be re-
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33 312 evaluated as a dynamic to static effort ratio. Tacking maneuvers lasted around 8 s while
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35 313 a gybe lasted around 12 s. High intensity efforts, linked to the demands of maneuvering
36
37 314 (Neville et al., 2009), occurred on a 1:14 ratio in NS and 1:50 in CR. Dynamic to static
38
39 315 ratio reached as high 1:10 when boats chose to sail a course close to shoreline (CR).
40
41 316 Hence, it can be assumed that the anaerobic energy system is significantly stressed
42
43 317 during TDF racing. However, the TDF competition also requires a good aerobic level to
44
45 318 endure the 15 days of sailing and to optimize recovery when racing (NS: 77 ± 14
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47 319 min.stage⁻¹; CR: 244 ± 35 min.stage⁻¹).

48 49 321 *Technical key performance indicators*

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52 322 GPS technology permits performance analysts to monitor external training load
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54 323 (Cummins et al., 2013) and collect data to identify technical and tactical performance
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56 324 indicators in sailing activities (Perez Turpin et al. 2009). Research has identified the key
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58 325 technical performance indicators in windsurfing (Anastasiou et al., 2019), match racing
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4 326 (Neville et al., 2009) and kiteboarding (Caimmi and Samprini, 2017). To the best of our
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6 327 knowledge, this is the first study to analyse such parameters in fleet racing.
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8
9 328 With regards to our results, we observed variability in the distance covered and
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11 329 time to finish a heat. Wind direction and wind speed influences the organisation committee
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13 330 in course settings (Perez Turpin et al., 2009). Nevertheless, it should be noted that sailing
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15 331 also relies on cognitive skills (Araújo et al., 2015) and that different racing strategies exist.
16
17 332 Teams must regularly analyse weather and oceanographic reports to determine the most
18
19 333 appropriate course (Thill, 1982). Other external parameters (e.g., position in the fleet,
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21 334 changes of racing conditions, placement of opponents on course) can provoke variations
22
23 335 and modifications in initial strategy (Araujo and Sepra, 1997; Ward, Williams and Bennett,
24
25 336 2002; Manzanares, Segado and Menayo, 2012).

26
27 337 Speed parameters have previously discriminated between successful and less
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29 338 successful athletes in other sailing competitions (Anastasiou et al., 2019; Caimmi and
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31 339 Samprini, 2017). This comforts our findings in that both average speed and maximal
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33 340 speed were significantly correlated to both race and TDF overall outcome. On the basis
34
35 341 of bio-informational data, one can assume that SB were more efficient in determining the
36
37 342 most favourable course to take in order to optimize boat speed. Pluijms et al. (2015) have
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39 343 investigated the difference in visual fixation behaviour between top and bottom-ranked
40
41 344 sailors. On the one hand, bottom ranked sailors focus their centre of attention on the boat
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43 345 and thus might discard important environmental information. On the other hand, top
44
45 346 ranked sailors, were capable of “feeling” the changes in boat speed and direction through
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47 347 mechanical and proprioceptive feedback. SB also displayed better starting performance
48
49 348 (rank and time gap at first mark) than LSB. Starting performance was significantly
50
51 349 correlated with race outcome and overall TDF ranking. This could be due to sailors
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53 350 changing their gaze to look for relevant environmental information that might enhance the
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55 351 boat’s performance (Pluijms et al., 2015). Indeed, if boats arrived first at the first mark they
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57 352 would not have to account for other information concerning opposing team position.
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354 *Profiling and physical key performance indicators*

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4 355 Although sailing has acquired research interest through important international
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6 356 events (i.e. Americas Cup and Olympic Games), none has analyzed the anthropometric,
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8 357 physical and physiological demands for multihull fleet racing. Hence, we can only compare
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10 358 our data to those of similar sailing events. The mean data for height and weight of the 21
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12 359 subjects (179.3 ± 7.3 cm and 74.8 ± 6.6 kg) are different to those found in other studies.
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14 360 Indeed, offshore sailors tended to be smaller and heavier (177 ± 7 cm and 78 ± 10 kg;
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16 361 Hurdie et al., 2014) whilst measures reported on the 2002 TDF outlined the smaller and
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18 362 lighter profiles of sailors at the time (173 ± 6 cm and 62.6 ± 9.3 kg; Leger et al., 2008).
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20 363 The body fat of athletes in the study hereby (12.91 ± 4 %) was similar to previously
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22 364 reported data of America's Cup sailors (13 ± 4 %; Neville et al., 2009), and seems within
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24 365 the range (10-15%) of international and Olympic dinghy sailors (Vangelakoudi et al., 2007;
25
26 366 Bojsen-Moller et al., 2007). Anthropometric characteristics vary according to competitive
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28 367 status, crew position, publishing date and sailing classification (Larsson et al., 1996).
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30 368 Surprisingly, there was no significant difference in anthropometric data in regards to crew
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32 369 position (Table 2). This could be the result of the race organization's choice to set the
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34 370 minimal total crew weight to 210 kg and supports findings by Neville et al., 2009 that
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36 371 highlights the modern sailors' strategy to reduce body fat of the whole crew as to maximize
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38 372 lean muscle mass for roles demanding higher physical output. This outlines the complexity
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40 373 when establishing normative data for sailing in general.

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42 374 The physical and physiological characteristics reported in the present study also
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44 375 varied when compared to other sailing studies. $\dot{V}O_{2max}$ of our present study (53.4 ± 8.5
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46 376 ml.mn⁻¹.kg⁻¹), seems to be (i) lower than in elite laser sailors (58.2 ± 4.7 ml.mn⁻¹.kg⁻¹;
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48 377 Castagna and Brisswaller, 2006), (ii) higher than finn sailors (47.6 ± 3.5 ml.mn⁻¹.kg⁻¹;
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50 378 Bojsen-Moller et al., 2007) and (iii) similar to America's Cup grinders (52.2 ± 4.6 ml.mn⁻¹.kg⁻¹;
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52 379 Bernardi et al., 2007). The differences outlined in these studies could be related to
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54 380 the effect induced by the various peculiar onboard activity and/or the use of various testing
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56 381 methodologies. Nevertheless, research has outlined the low aerobic demands during a
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58 382 dinghy regatta (Portier et al., 2003). Indeed, sailors participating on TDF engage in high
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60 383 intensity hoisting and trimming actions when maneuvering. Between the different
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62 384 maneuvers, the sailors are involved in quasi-isometric hiking. Previous studies showed a
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64 385 significantly decreased oxygenation pattern in the m. Vastus Lateralis during hiking
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4 386 (inherent to isometric contractions > 30% maximal voluntary contraction), indicating an
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6 387 imbalance between oxygen supply and demand, and probably due to restricted muscle
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8 388 blood flow (Bourgois et al., 2016). The sailors undertaking the MRWT-MPO test in this
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10 389 study (565.9 ± 97.9 W) held similar anaerobic capacity than highly trained college level
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12 390 rowers (548.97 ± 95.57 W; Shaharudin and Zanutto, 2014). This comforts our
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14 391 understanding that TDF sailors rely significantly on anaerobic energy delivery during
15
16 392 racing.

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18 393 Lower body power was assessed using SJ and CMJ protocols. Few other studies
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20 394 have analyzed such parameters on sailors. Indeed, only one has assessed national level
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22 395 sailors for lower body power (Tan et al., 2006) and found similar results to the present
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24 396 study (36.0 ± 6.2 vs 34.0 ± 4.0 cm) on the SJ. Nevertheless, it seems that no correlation
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26 397 between jumping performance and hiking potential exists (Tan et al., 2006). Hiking is
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28 398 characterized by strong isometric contractions and coactivation of the muscles involved:
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30 399 quadriceps, hamstrings, abdominal and paravertebral muscles (Larsson et al., 1996; Tan
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32 400 et al., 2006). Numerous studies have analyzed isokinetic muscle strength of knee, hip and
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34 401 trunk flexors and extensors of elite level sailors (Aagaard et al., 1998; Chicoy and
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36 402 Encarnacion-Martinez, 2015). These studies have highlighted the high demands of these
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38 403 specific strengths on hiking performance. In the present study, to assess maximal
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40 404 isometric strength of the lower body, an IMTP test was performed. To date, this is the first
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42 405 study to use such a protocol in an elite sailing environment. Relative strength should be
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44 406 considered when assessing sailors, or other sports, where body weight is regulated by
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46 407 competition rules. Isometric maximal voluntary force, using the IMTP test, has been linked
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48 408 to functional performance in sport (Ran-Wang et al. 2016). We aimed at analyzing
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50 409 isometric strength at hip/knee angles like those of other sailing studies (Chicoy and
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52 410 Encarnacion-Martinez, 2015) by using the IMTP. Interestingly, maximal IMTP
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54 411 discriminated between SA and LSA when the results were compared relatively to
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56 412 bodyweight (IMTP_w). IMTP_w performance was significantly correlated ($r=0.41$; $p<0.01$)
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58 413 with rank on NS courses. These results suggest that a high level of relative strength is
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60 414 necessary in TDF sailors, and supports the findings in other studies analyzing the
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62 415 relationship between lower body strength and sailing performance (Blackburn and
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64 416 Hubinger, 1995).
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4 417 Trimming and hoisting actions requires powerful and energetic movements on the
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6 418 sheets (Bay and Larsson, 2013). By doing so, sailors increase the amount of apparent
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8 419 wind that covers the sail and, thus, increase boat speed. Indeed, it was thought that sailors
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10 420 participating in the TDF would have high amounts of maximal strength due to the
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12 421 predominance of pulling actions necessary when maneuvering the boat. Differences can
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14 422 be outlined for the one repetition maximum between Americas Cup sailors (99.41 ± 5.4
15 423 kg; Pearson et al., 2009) and TDF sailors of this present study (77.5 ± 13.0 kg).
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17 424 Nevertheless, it should be noted that the America's cup sailors were heavier (97.8 ± 12.5
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19 425 vs 74.8 ± 6.6 kg). Bar velocity at fixed loads was also evaluated and turned out to be
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21 426 significantly different between SA and LSA at 20 kg loads. Neville and collaborators (2009)
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23 427 reported that successful boats maneuvered faster than less successful boats. Faster bar
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25 428 velocity at submaximal loads could be directly correlated to hoisting/trimming efficiency
26 429 and, thus, sailing performance through faster maneuvers. BP_{mpv20} was in fact significantly
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28 430 correlated to racing outcome (NS and CR) and TDF final ranking ($r=.80$; $p<0.05$). Future
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30 431 research should therefore aim at establishing associations between bar velocities at fixed
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32 432 loads with hoisting actions.

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34 433 Handgrip strength has received a considerable amount of interest in past research.
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36 434 Indeed, it has been linked to performance in many sports (Cronin et al., 2017). Significant
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38 435 decreases in grip strength between pre- and post-sailing training sessions have been
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40 436 reported in junior male semi-elite sailors (Bateup et al., 2016). The TDF sailors (61.1 ± 9.5
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42 437 kg) reported stronger HGS_{Dom} than collegiate dinghy sailors (48.28 ± 5.31 kg; Pultur, 2011).
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44 438 These results outline the high mechanical stress placed on forearms when maneuvering
45 439 TDF boats. HGS_{Dom} was found to significantly discriminate between SA and LSA. It was
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47 440 also correlated to racing outcome (NS and CR). These results could indicate more
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49 441 efficiency to maneuver the D24 at higher speeds (i.e. optimized gripping ease against high
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51 442 resistance in sheets and cranks). It would seem interesting to analyze the acute and
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53 443 chronic load effects of sailing on handgrip strength.

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55 444 An interesting finding of this study was that no significant difference was found
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57 445 between crew positions for physical and physiological parameters. This could indicate an
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59 446 equal importance of overall fitness of TDF sailors to maneuver the boat. Indeed, it was
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4 447 not rare to see sailors switch position when racing or during specific maneuvers
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6 448 throughout the TDF. Comparison of physical and physiological parameters from 21 elite
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8 449 sailors indicated that SA had greater strength (HGS_{Dom}), muscular voluntary contraction
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10 450 ($IMTP_W$) and power (BP_{mpv20}) compared to LSA. Differences were most marked between
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12 451 trimmers ($IMTP_W$, BP_{mpv20} , BP_{mpv30} and BP_{mpv40}) and bowmen (BP_{mpv20}) which are primarily
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14 452 responsible for trimming and material handling (sails, ropes and cranks). A possible
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16 453 explanation highlighting the difference in HGS_{Dom} found in this study could result from
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18 454 higher training loads on-water and off- of SA (Bateup et al., 2016).
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21 22 23 456 **Study limitations**

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25 457 Some limitations in the present study have been identified during the analysis process.
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27 458 First, the sample size of 21 elite level sailors accounted for 6 fully crewed boats out of 23.
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29 459 Testing more crew members may have permitted to perform more significant correlational
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31 460 analysis between crew characteristics, as a mean or sum, and ranking. Second, as
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33 461 previously mentioned, sailing relies on bio-informational and strategic qualities to perform.
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35 462 Indeed, overall and specific sailing experience was not accounted for and could have
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37 463 influenced performance and account for discrimination of success.
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40 465 **Conclusion**

41
42 466 Overall, the findings have identified multiple variables (technical and physical) that
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44 467 discriminate between successful and less successful athletes/boats. The results can be
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46 468 used as normative data to compare, detect and guide athletes in their preparation for
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48 469 performance. The present study highlights successful sailors having stronger grip
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50 470 strength, more powerful bench-pull and higher IMTP than their less successful
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52 471 counterparts. Successful boats displayed a faster average speed, maximal speed and
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54 472 more efficient starting performance. Nevertheless, these findings should be applied with
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56 473 caution to other populations (i.e. youths, less experimented sailors and other sailing
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58 474 categories).
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476 **Practical applications**

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

487 **Acknowledgements**

488 The investigators would like to acknowledge the Sailing Federation (France) and
489 Georacing® for their continued collaboration.

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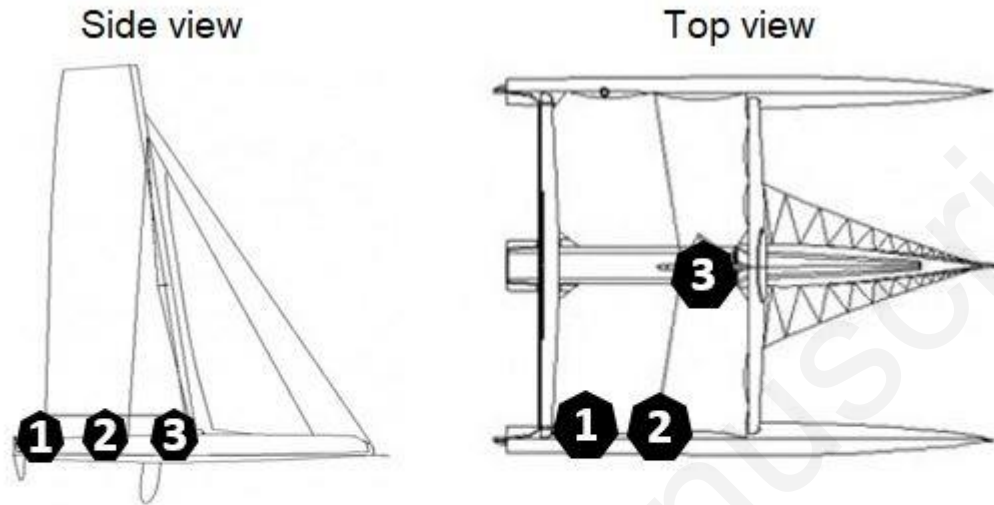
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- 1. **Helmsman:** responsible for manoeuvring the boat by acting directly on the rudders.
- 2. **Trimmer:** Trims the shape of the sails by acting on the cranks.
- 3. **Bowman:** Responsible for the hoisting and the dropping of the sails.

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.

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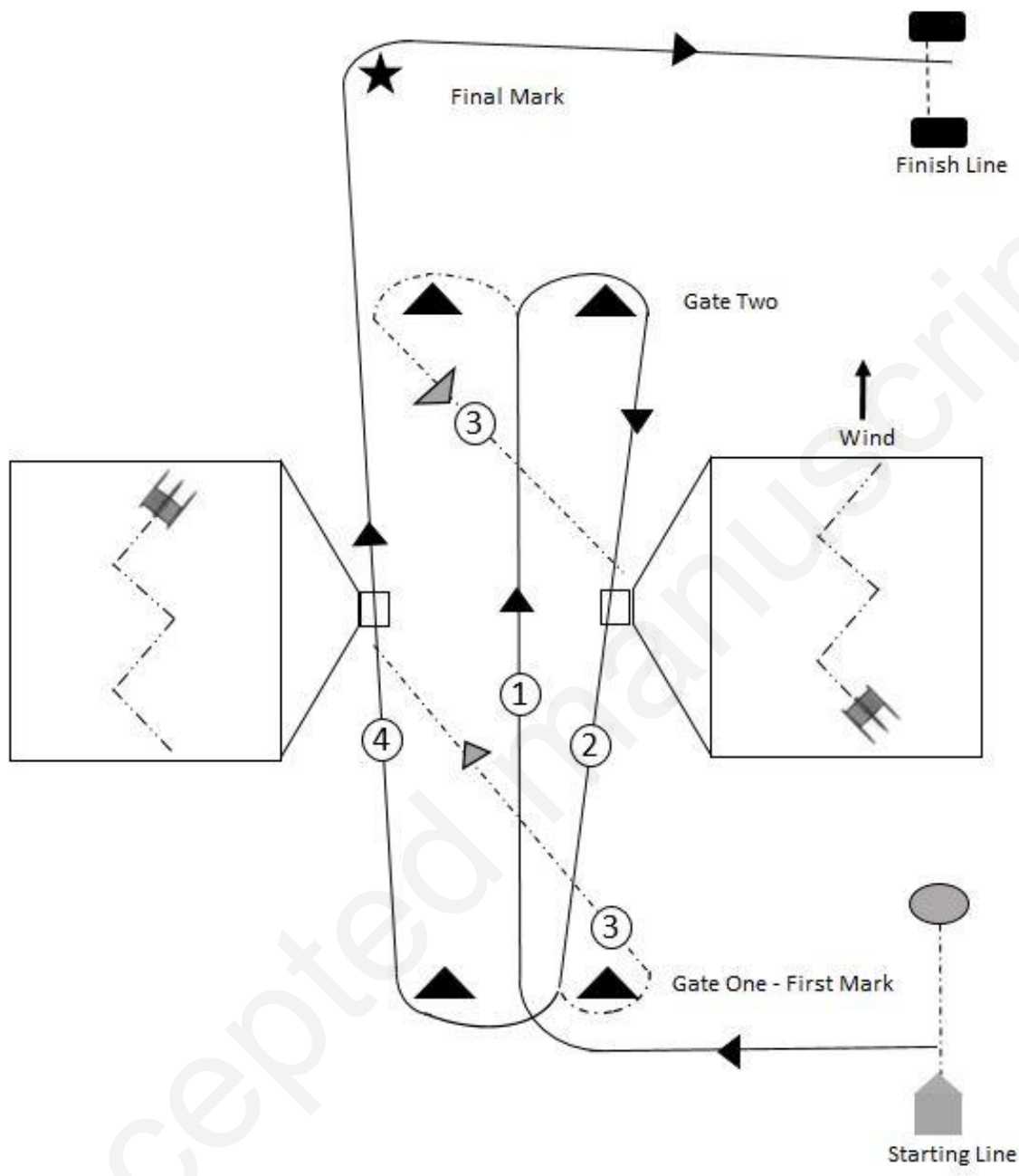


Figure 2. A typical Tour de France nautical stadium course. (1) Represents the downwind portion and (2) the upwind portion. (1) And (2) can be sailed up to three times according to race committee. Teams must go through the gates and can chose to round either mark (3). (4) Represents the final straight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

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65**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 Skinfol d (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 _{Do} m (kg)	HGS _{Su} m (kg)	SJ _H (cm)	CMJ _H (cm)	IMTP (N)	IMTP _W (N.kg ⁻¹)	MRWT- MPO (W)	BP _{1R} M (kg)	BP _{MPV2} o (m.s ⁻¹)	BP _{MPV3} o (m.s ⁻¹)	BP _{MPV4} o (m.s ⁻¹)	BP _{MPV5} o (m.s ⁻¹)	VO _{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; VO_{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)

References

- 515
516 Aagaard, P., Beyer, N., Simonsen, E. B., Larsson, B., Magnusson, S. P. & Kjaer, M.
517 (1998). Isokinetic muscle strength and hiking performance in elite sailors. *Scandinavian*
518 *Journal of Medicine & Science in Sports*, 8, 138-144.
- 519 Amann, M., Subudhi, A., and Foster, C., (2004). Influence of Testing Protocol on
520 Ventilatory Thresholds and Cycling Performance. *Medecine and Science in Sports and*
521 *Exercise*, 36, No. 4, 613–622.
- 522 Anastasiou, A., Jones, T., Mullan, P., Ross, E., & Howatson, G. (2019). Descriptive
523 analysis of Olympic class windsurfing competition during the 2017-2018 regatta
524 season. *International Journal of Performance Analysis in Sport*, 19(4), 517–529.
- 525 Araújo, D., & Sepra, S. (1997). Towards a construction of methodological design to
526 measuring decision making in externally paced sport : the case of sailing. In *In Innovations*
527 *in sport psychology : linking theory and practice : proceedings, pt. I., The Zinmann College*
528 *of Physical Education and Sport Sciences, The Wingate Institute for Physical Education*
529 *and Sport, p.76-78.*
- 530 Araújo, D., Davids, K., Diniz, A., Rocha, L., Santos, J. C., Dias, G., & Fernandes, O.
531 (2015). Ecological dynamics of continuous and categorical decision-making: The regatta
532 start in sailing. *European Journal of Sport Science*, 15(3), 195–202.
- 533 Balsalobre-Fernandez, C., Glaister, M., & Lockey, R. A. (2015). The validity and reliability
534 of an iPhone app for measuring vertical jump performance. *Journal of Sports Sciences*,
535 1–6.
- 536 Bateup, B., Thornton, H., Withers, S. & Duthie, G. (2016) The Influence of Training Load
537 on Markers of Fatigue in Junior Male Semi-Elite Sailors. *Journal of Australian Strength &*
538 *Conditioning*, 24(6), 21–22.
- 539 Batterham, AM. and Hopkins, WG. (2006). Making meaningful inferences about
540 magnitudes. *International Journal of Sports Physiology and Performance*, 1, 50–57.
- 541 Bay, J., & Larsson, B. (2013). Bay testen. En fysiologisk performance test for 49'er gaster
542 [A physiological performance test for 49'er crewmen] (Unpublished thesis). Copenhagen:
543 Team Danmark and Department of Nutrition, Exercise and Sports Sciences, University of
544 Copenhagen/Team Danmark.
- 545 Bernardi, M., Quattrini, F., Rodio, A., Fontana, G., Madaffari, A., Brugnoli, M. & Marchetti,
546 M. (2007). Physiological characteristics of America's Cup sailors. *Journal of Sports*
547 *Sciences*, 25, no. 10, 1141–1152.
- 548 Blackburn, MJ., & Hubinger, I. (1995). Determination of physiological profiles and exercise
549 training programs for competitive dinghy sailors. *National Sports Research Centre*, 1-16.

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65

Bojsen-Møller, J., Larsson, B., Magnusson, S. P., & Aagaard, P. (2007). Yacht type and crew-specific differences in anthropometric, aerobic capacity, and muscle strength parameters among international Olympic class sailors. *Journal of Sports Sciences*, 25(10), 1117–1128.

Bourgois, J. G., Callewaert, M., Celie, B., De Clercq, D., & Boone, J. (2016). Isometric quadriceps strength determines sailing performance and neuromuscular fatigue during an upwind sailing emulation. *Journal of Sports Sciences*, 34(10), 973-979.

Brozek J, Grande F, Anderson JT, Keys A. Densitometric analysis of body composition: revision of some quantitative assumptions. *Ann. N. Y. Acad. Sci.* 1963;110:113–140.

Caimmi, G., & Semprini, G. (2017). Heart rate and GPS data analysis of kiteboard course racing during the Italian Championship. *Sport Sciences for Health*, 13(1), 79–85.

Castagna, O., & Brisswalter, J. (2007). Assessment of energy demand in Laser sailing: influences of exercise duration and performance level. *European Journal of Applied Physiology*, 99(2), 95–101.

Chicoy, I. & Encarnación-Martínez, A. (2015). Determining Factors in the Performance of Hiking in Dinghy Sailing: A Literature Review. *Motricidad: European Journal of Human Movement*, 34, 15–33.

Cronin, J., Lawton, T., Harris, N., Kilding, A. & McMaster, DT. (2017). A Brief Review of Handgrip Strength and Sport Performance. *Journal of Strength & Conditioning Research*, 31(11), 3187–3217.

Cummins, C., Orr, R., O'Connor, H., & West, C. (2013). Global Positioning Systems (GPS) and Microtechnology Sensors in Team Sports: A Systematic Review. *Sports Medicine*, 43(10), 1025–1042.

Dieli-Conwright, C., Jensky, N. & Battaglia, G. and McCauley, S. and Todd Schroeder, E. (2009). Validation of the CardioCoachCO2 for Submaximal and Maximal Metabolic Exercise Testing. *Journal of strength and conditioning research*, 23, 1316-20.

Duthie, G. M. (2006). A Framework for the Physical Development of Elite Rugby Union Players. *International Journal of Sports Physiology & Performance*, 1(1), 2–13.

Fernandez-Fernandez, J., Sanz-Rivas, D. and Mendez-Villanueva, A. (2009). A Review of the Activity Profile and Physiological Demands of Tennis Match Play. *Strength and Conditioning Journal*, 31(4), 15–26.

Haff, G., Nimphius, S. and Sheppard, JM. (2013). The reliability of isometric force-time variables collected on a portable mid-thigh pull testing device. *Journal of Strength Conditioning Research*, 27(10), 98–99.

Hurdiel, R., Van Dongen, H., Aron, C., McCauley, P., Jacolot, L. and Theunynck, D. (2014). Sleep restriction and degraded reaction-time performance in Figaro solo sailing races. *Journal of Sports Sciences*, 32(2), 172–174.

- 1
2
3
4 587 Jackson, AS. and Pollock, ML. (1978). Generalized equations for predicting body density
5 588 of men 1978. *British Journal of Nutrition*, 40, 497-504.
- 7 589 Larsson, B., Beyer, N., Bay, P., Blond, L., Aagaard, P. and Kjaer, M. (1996). Exercise
8 performance in elite male and female sailors. *International Journal of Sports Medicine*,
9 590 17(7), 504–508.
- 12 592 Léger, D., Elbaz, M., Raffray, T., Metlaine, A., Bayon, V., & Duforez, F. (2008). Sleep
13 593 management and the performance of eight sailors in the Tour de France à la voile yacht
14 594 race. *Journal of Sports Sciences*, 26(1), 21–28.
- 17 595 Manzanares Serrano, A., Segado Segado, F., & Menayo Antúnez, R. (2012). Factores
18 596 determinantes del rendimiento en vela deportiva: revisión de la literatura. / Decisive
19 597 factors in Sailing Performance: Literature review. *Cultura, Ciencia y Deporte*, 7(20), 125–
20 598 134.
- 23 599 Marfell-Jones, M., Olds, T., Stewart, A., & Carter, J. E. L. (2006). International standards
24 600 for anthropometric assessment. Potchefstroom, South Africa: ISAK.
- 26 601 Neville, V., Calefato, J., Pérez-Encinas, C., Rodilla-Sala, E., Rada-Ruiz, S., Dorochenko,
27 602 P., & Folland, J. (2009). America's Cup yacht racing: Race analysis and physical
28 603 characteristics of the athletes. *Journal of Sports Sciences*, 27(9), 915–923.
- 31 604 Pearson, S. N., Hume, P. A., Cronin, J. B., & Slyfield, D. (2009). Strength and Power
32 605 Determinants of Grinding Performance in America's Cup Sailors. *Journal of Strength &
33 606 Conditioning Research*, 23(6), 1883–1889.
- 35 607 Pérez-Turpin, J. A., Cortell-Tormo, J. M., C. Suárez-Llorca, Andreu-Cabrera, E., Llana-
36 608 Belloch, S., & Pérez-Soriano, P. (2009). Relationship between Anthropometric
37 609 Parameters, Physiological Responses, Routes and Competition Results in Formula
38 610 Windsurfing. *Acta Kinesiologiae Universitatis Tartuensis*, 14, 95–110.
- 41 611 Peterson Silveira, R., Stergiou, P., Carpes, FP., Castro, FA., Katz, L and Stefanyshyn,
42 612 DJ. (2017). Validity of a portable force platform for assessing biomechanical parameters
43 613 in three different tasks. *Sports Biomechanics*, 16(2), 177–186.
- 46 614 Pluijms, J. P., Cañal-Bruland, R., Hoozemans, M. J. M., & Savelsbergh, G. J. P. (2015).
47 615 Visual search, movement behaviour and boat control during the windward mark rounding
48 616 in sailing. *Journal of Sports Sciences*, 33(4), 398–410.
- 50 617 Portier, H., & Guezennec, C. Y. (2003). Estimation de la depense energetique lors d'une
51 618 regate en deriveur. / Oxygen cost assessment during small craft competition. *Science &
52 619 Sports*, 18(2), 111–113.
- 55 620 Pular, A. (2011). Determination of physical and physiological profiles of international elite
56 621 sailors. *African Journal of Business Management*, 5 (8), 3071-3075.
- 58 622 Ran Wang, Hoffman, JR., Tanigawa, S., Miramonti, AA., La Monica, MB., Beyer, KS.,
59 623 Church, D., Fukuda, D. and Stout, JR. (2016). Isometric mid-thigh pull correlates with
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60
61
62
63
64
65

624 strength, sprint, and agility performance in collegiate rugby union players. *Journal of*
625 *Strength and Conditioning Research*, 30(11), 3051–3056.

626 Riechman, S. E., Zoeller, R. F., Balasekaran, G., Goss, F. L., & Robertson, R. J. (2002).
627 Prediction of 2000 m indoor rowing performance using a 30 s sprint and maximal oxygen
628 uptake. *Journal of Sports Sciences*, 20(9), 681–687.

629 Rocznik, R., Maszczyk, A., Stanula, A., Czuba, M., Pietraszewski, P., Kantyka, J., &
630 Starzyński, M. (2013). Physiological and physical profiles and on-ice performance
631 approach to predict talent in male youth ice hockey players during draft to hockey
632 team. *Isokinetics & Exercise Science*, 21(2), 121–127.

633 Sánchez-Medina, L., González-Badillo, J. J., Pérez, C. E., & Pallarés, J. G. (2014).
634 Velocity- and Power-Load Relationships of the Bench Pull vs. Bench Press
635 Exercises. *International Journal of Sports Medicine*, 35(3), 209–216.

636 Shaharudin, S. and Zanotto, D. and Agrawal, S. (2014). Muscle Synergy during Wingate
637 Anaerobic Rowing Test of Collegiate Rowers and Untrained Subjects. *International*
638 *Journal of Sports Science*, 4, 165-172.

639 Spiro SG. (1977). Exercise testing in clinical medicine. *Br J Dis Chest*. Jul;71(3):145-72

640 Svantesson, U., Nordé, M., Svensson, S., & Brodin, E. (2009). A comparative study of the
641 Jamar® and the Grippit® for measuring handgrip strength in clinical practice. *Isokinetics*
642 *& Exercise Science*, 17(2), 85–91.

643 Tan, B., Aziz, A. R., Spurway, N. C., Toh, C., Mackie, H., Wei Xie, James Wong, Fuss, F.
644 K., Kong Chuan Teh, Xie, W., Wong, J., & Teh, K. C. (2006). Indicators of maximal hiking
645 performance in Laser sailors. *European Journal of Applied Physiology*, 98(2), 169–176.

646 Thill, E. (1982). La detection sportive a partir de criteres psychologiques. In *Dans, Rioux,*
647 *G. et Thill, E. (eds.), Competition sportive et psychologie: Journees europeennes de*
648 *psychologie du sport, Paris, Chiron, c1982, p. 77-94.*

649 Vangelakoudi, A., Vogiatzis, I., & Geladas, N. (2007). Anaerobic capacity, isometric
650 endurance, and Laser sailing performance. *Journal of Sports Sciences*, 25(10), 1095–
651 1100.

652 Vehrs, P. R., Keller, D. M., George, J. D., Hager, R. L., & Fellingham, G. W. (2007).
653 Monitoring O₂max during Fourteen Weeks of Endurance Training Using the
654 Cardiocoach. *Journal of Strength & Conditioning Research*, 21(1), 62–66.

655 Ward, P., Williams, A. M., & Bennett, S. J. (2002). Visual search and biological motion
656 perception in tennis. *Research Quarterly for Exercise & Sport*, 73(1), 107–112.