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Optimal Mechanical Force-Velocity Profile for Sprint Acceleration Performance

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14

15 **ABSTRACT**

16 The aim was to determine the respective influences of sprinting maximal power output
17 (P_Hmax) and mechanical Force-velocity (F-v) profile (i.e. ratio between horizontal force
18 production capacities at low and high velocities) on sprint acceleration performance. A
19 macroscopic biomechanical model using an inverse dynamics approach applied to the athlete's
20 centre of mass during running acceleration was developed to express the time to cover a given
21 distance as a mathematical function of P_Hmax and F-v profile. Simulations showed that sprint
22 acceleration performance depends mainly on P_Hmax , but also on the F-v profile, with the
23 existence of an individual optimal F-v profile corresponding, for a given P_Hmax , to the best
24 balance between force production capacities at low and high velocities. This individual optimal
25 profile depends on P_Hmax and sprint distance: the lower the sprint distance, the more the
26 optimal F-v profile is oriented to force capabilities and vice versa. When applying this model
27 to the data of 231 athletes from very different sports, differences between optimal and actual F-
28 v profile were observed and depend more on the variability in the optimal F-v profile between
29 sprint distances than on the interindividual variability in F-v profiles. For a given sprint
30 distance, acceleration performance (<30 m) mainly depends on P_Hmax and slightly on the
31 difference between optimal and actual F-v profile, the weight of each variable changing with
32 sprint distance. Sprint acceleration performance is determined by both maximization of the
33 horizontal power output capabilities and the optimization of the mechanical F-v profile of sprint
34 propulsion.

35

36 **Key Words:** horizontal force production; all-out running; maximal power output;
37 biomechanics

38

39 INTRODUCTION

40 Sprint running acceleration is a key performance determinant in many sports (e.g. track and
41 field events or team sports) and refers to all-out efforts aiming at covering distance in the
42 shortest time possible (or the largest distance in a given time of action). Forward acceleration
43 capabilities have gained interest over the last decade in sport sciences, notably because
44 individual top speed is rarely reached by athletes during games (e.g., in soccer or rugby).
45 Therefore, examining the factors that determine all-out sprint acceleration performance may
46 inform scientists and practitioners about the physical characteristics underlying sprinting
47 performance.

48 The effect of force production qualities on sprint acceleration performance (sprint times from
49 10 to 100m) has been widely studied through lower limb strength output, notably in squat, leg
50 press or jumps (e.g. ¹⁻³). Overall, sprint times were shown to be correlated to lower-limb
51 maximal strength and power output, with an overall decreasing magnitude when sprint distance
52 and subject level increase. However, in these studies, the strength indexes did not cover the
53 entire spectrum of force-velocity qualities, notably the force production capacity at high
54 velocity was not thoroughly assessed. Moreover, force production capabilities were not sprint-
55 specific but only inferred from lower limb gym-based strength indexes. From basic principles
56 of dynamics, the motion of one athlete's centre of mass (CoM) mainly depends on the ground
57 reaction force applied on it, the latter resulting directly from the external force the athlete
58 produced onto the ground ⁴. Although running (with support and aerial phases) is possible only
59 if net force is developed in the vertical direction, the forward acceleration of the CoM from one
60 step to another is directly related to the net force developed by the athlete onto the ground in
61 the horizontal, antero-posterior direction (backward so that the reaction is directed forward) ⁴.
62 All other things equal, the greater this net horizontal force component relative to body mass,
63 the higher the acceleration of the body in the forward direction, *ceteris paribus* ⁴. Force
64 production during sprinting has been widely described in studies analysing only some steps
65 during the acceleration phase or steady-speed (i.e., not accelerated) runs including top speed ⁵⁻
66 ⁷. Collectively, they showed (i) that early acceleration performance is related to high horizontal
67 propulsive force ^{4,5}, and (ii) that the ability to maintain maximal running velocity is associated
68 to high mass-specific vertical force applied over very short support time during the constant top
69 speed phase ^{6,7}. Based on ground reaction force measurement over an entire acceleration phase,
70 recent studies confirmed the importance of the net horizontal force component to explain inter-

71 athlete's differences in sprint acceleration performance (Rabita et al 2015, Morin et al 2012,
72 Colyer et al 2018).

73 Consequently, sprint running acceleration performance depends on the athlete's capacity to
74 produce net "horizontal force" onto the ground over each step. A macroscopic view of these
75 capacities is given by the force-velocity (F-v) and power-velocity (P-v) relationships in
76 sprinting^{8,9}. Even if terminology is similar, sprinting F-v and P-v relationships are far from the
77 original intrinsic muscle F-v relationships reported on isolated muscle by Hill and colleagues
78¹⁰ since they represent here the external horizontal force production capacities of the overall
79 body during sprint acceleration. They integrate other neuromuscular and biomechanical
80 mechanisms than those inherent to the muscle fibres only: basically mechanisms associated to
81 the transmission efficiency between the muscle force and the external force¹¹. These
82 relationships describe the change in the athlete's maximal horizontal external force and the
83 associated power production capabilities when running speed increases. As previously
84 described for other multi-joint movements (pedalling, squat jump, leg press)¹²⁻¹⁷, sprinting F-
85 v and P-v relationships provide an objective quantification of force/power production abilities
86 through the maximal power output an athlete can develop in the horizontal direction (P_Hmax ,
87 power capabilities), the theoretical maximal horizontal force an athlete can produce onto the
88 ground (F_H0 , force capabilities) and the theoretical maximal velocity until which the athlete is
89 still able to produce positive net horizontal force (v_H0 , velocity capabilities). Conceptually,
90 F_H0 and v_H0 are independent and are associated to different physical and technical abilities
91 related to producing high amount of horizontal force at low running velocities (F_H0) and
92 horizontal force at high velocities (v_H0). These different key mechanical variables result from
93 the complex integration of the different physiological, neural and biomechanical mechanisms
94 involved in the total external force production and characterizing different athlete's abilities¹⁴⁻
95¹⁷. Moreover, when focusing on sprint running movement, F-v and P-v relationships are specific
96 to running acceleration propulsion and in turn also integrate the ability to apply the external
97 force "effectively" (i.e. with a horizontal orientation in the antero-posterior direction) onto the
98 ground^{8,18,19}. These relationships thus refer to overall sprinting propulsion capacities rather
99 than muscle properties only. The ratio between F_H0 and v_H0 corresponds to the athlete's
100 mechanical F-v profile (S_{Fv} , slope of the F-v linear relationship)^{12,20}. Interestingly, as for
101 vertical jumping²¹, two athletes can present very different F-v profiles with the same maximal
102 power capability (P_Hmax). Among these different force production capacities, scientists,
103 coaches or athletes wonder which one is more important (if any) for sprint running acceleration

104 performance (mostly quantified through time to cover a given distance)? One of the main
105 questions for sport practitioners is to determine where to place the training “cursor” and how to
106 program training within the continuum between these two extreme force production capacities
107 of the F-v profile: maximal horizontal force at low and high velocities.

108 In the last decade, several studies explored the mechanical determinants of sprint running
109 acceleration through sprinting power-force-velocity relationships ^{8,18,19,22}. The main findings of
110 these studies were that sprint performance (40-m or 100-m times, maximal speed or 4-s
111 distance) depends on the mean horizontal power and force produced over the acceleration phase
112 ^{8,18,19,23}. This has been shown to be related to a high athlete’s P_Hmax associated to a high v_H0 ,
113 notably due to a high mechanical effectiveness, in recreational sportsmen ¹⁸, old trained
114 sprinters ²⁴, high level ^{8,19,23} to world class men and women sprinters ²². Consequently, P_Hmax
115 seems to be the main determinant of sprint acceleration performance, notably due to a high
116 ability to produce horizontal force at high velocities rather than a high maximal horizontal force
117 production at low velocities. However, these studies only focus on relatively long sprint
118 accelerations (40-m to 100-m times, 4-s distance) and did not assess the relative importance of
119 each extremum of the horizontal force production capacities (F_H0 versus v_H0), i.e. of
120 mechanical F-v profile (S_{Fv}), according to the sprint distance and independently from the effect
121 of P_Hmax . Does the increase in performance depend only on an overall shift of the F-v
122 relationship upwards and to the right (i.e. an increase in P_Hmax)? Or could a change in its slope
123 (i.e. an increase or decrease in S_{Fv}) independently from its overall position also contribute to
124 performance improvement? And if so, to what extent for each sprint distance?

125 The question of the effect of the mechanical F-v profile on performance, independently of the
126 power capacities, has been studied for ballistic push-off exercises such as jumping ^{12,25}. The
127 maximal take-off velocity was shown to depend on both lower limb maximal power output
128 (relative to body mass) and F-v profile, with the existence of an individual optimal F-v profile
129 representing, for a given maximal power output, the best balance between force and velocity
130 capacities maximizing the performance. The higher the maximal power and the lower the
131 difference between actual and optimal F-v profile, the higher the jumping performance ^{12,21,25}.
132 Given the differences in movement modalities between acyclic single push-off jumping and
133 cyclic multiple steps running movements, this concept, based on a specific jumping
134 biomechanical model, could not be directly applied to sprint acceleration. The existence of such
135 an effect of F-v profile, and notably the existence of an optimal profile in sprint running, is still
136 unknown. This could be of great interest for scientists to better understand the mechanical

137 determinants of running acceleration, but also for sport practitioners to help improving sprint
138 performance.

139
140 The overarching aim of this study was to determine the respective influences of sprinting
141 maximal power output and mechanical F-v profile on sprint acceleration performance. Since
142 the importance of horizontal force production capacities at low or high velocities can be
143 expected to depend on the sprint acceleration distance, the secondary aim of this study was to
144 investigate to what extent the effects of maximal power output and F-v profile (if any) depend
145 on the sprint acceleration distance (until to 30 m). To address these aims, a macroscopic
146 biomechanical model was developed, simulated, and then applied on experimental data to
147 quantify the respective contributions of maximal power output and mechanical F-v profile on
148 acceleration performance of athletes from different sports and over different distances.

149

150

151 **THEORETICAL BACKGROUND**

152 This section, associated to the first aim, is an analysis of kinematics and kinetics of the runner's
153 body CoM during a linear sprinting acceleration starting from null velocity using a macroscopic
154 inverse dynamics approach aiming to be the simplest possible and only focusing on the net step-
155 averaged horizontal component of the external force (and associated power output) ^{20,26}. All
156 variables presented in this section are modelled over time, without considering intra-step
157 changes, and thus correspond to step-averaged values (over contact plus subsequent aerial
158 times).

159

160 Net horizontal antero-posterior ground reaction force as a function of maximal running 161 velocity and acceleration time constant

162 During an all-out sprint running acceleration, horizontal velocity (v_H , in $\text{m}\cdot\text{s}^{-1}$)-time (t) curve
163 has long been shown to systematically follow a mono-exponential function for recreational to
164 highly trained sprinters ^{20,26,27}:

$$165 \quad v_H(t) = v_H \text{max}. (1 - e^{-t/\tau}) \quad [1]$$

166 with $v_H \text{max}$ the maximal velocity reached at the end of the acceleration (in $\text{m}\cdot\text{s}^{-1}$) and τ the
167 acceleration time constant (in s). The horizontal position (x_H , in m) and acceleration (a_H , in

168 m.s⁻²) of the body CoM as a function of time during the acceleration phase can be expressed
169 after integration and derivation of $v_H(t)$ over time, respectively, as follows ²⁰:

$$170 \quad x(t) = v_Hmax. \left(t + \tau. e^{-\frac{t}{\tau}} \right) - v_Hmax. \tau \quad [2]$$

$$171 \quad a_H(t) = \left(\frac{v_Hmax}{\tau} \right). e^{-\frac{t}{\tau}} \quad [3]$$

172 Applying the fundamental laws of dynamics in the horizontal direction, the net horizontal
173 antero-posterior ground reaction force relative to body mass (BM) and applied to the body CoM
174 (F_H , in N.kg⁻¹) can be modelled over time as:

$$175 \quad F_H(t) = a_H(t) + F_{aero}(t) \quad [4]$$

176 with $F_{aero}(t)$ the BM-relative aerodynamic drag (in N.kg⁻¹) to overcome during sprint running
177 which is proportional to the square of the velocity of air relative to the runner:

$$178 \quad F_{aero}(t) = k. v_H(t)^2 \quad [5]$$

179 with k the runner's aerodynamic friction coefficient ^{20,28}, expressed relative to BM, considering
180 a situation without any wind.

181

182 From equation (1),

$$183 \quad v_Hmax. e^{-t/\tau} = v_Hmax - v_H(t) \quad [6]$$

184 So, from equations [4], [5], [6], F_H can be modelled as:

$$185 \quad F_H(t) = \frac{v_Hmax}{\tau} - \frac{1}{\tau} v_H(t) + k. v_H(t)^2 \quad [7]$$

186

187 Maximal running velocity and acceleration time constant as a function of force production 188 abilities

189 The linear sprinting acceleration performance can be represented by the distance covered within
190 a given time (equation (2)), which depends on two parameters characterizing two different (but
191 not independent) parts of the performance: v_Hmax and τ . This section first aims at expressing
192 these two parameters as a function of force production abilities F_H0 and v_H0 , and then as a
193 function of P_Hmax and S_{Fv} .

194 From equation (7), the theoretical maximum F_H than can be developed at null v_H (F_H0 , in N.kg⁻¹) can be expressed as:

$$196 \quad F_H0 = \frac{v_Hmax}{\tau} \quad [8]$$

197 And so v_Hmax can be expressed by:

$$198 \quad v_Hmax = \tau \cdot F_H0 \quad [9]$$

199

200 The theoretical maximal velocity until which F_H can be developed (v_H0) can be obtained
201 solving $F_H(t) = 0$ (equation (7)) with $v_H(t) = v_H0$. This gives:

$$202 \quad v_H0 = \frac{1}{2k\tau} (1 - \sqrt{1 - 4k \cdot \tau \cdot v_Hmax}) \quad [10]$$

203

204 From equations (9) and (10), and isolating v_Hmax gives:

$$205 \quad v_Hmax = \frac{F_H0 \cdot v_H0}{k \cdot v_H0^2 + F_H0} \quad [11]$$

206

207 From equations (9) and (11), and isolating τ gives:

$$208 \quad \tau = \frac{v_H0}{k \cdot v_H0^2 + F_H0} \quad [12]$$

209

210 Despite equation (7) showed that F-v relationship is mathematically described by a polynomial
211 function, the simplifying assumption of a linear F-v relationship was used here based on the
212 previously reported experimental data on human multi-joint movements^{12,14} and sprinting^{8,29}
213 (the induced-errors were further tested and discussed in the following sections, see
214 Supplementary Material). In this case, the maximal horizontal power output (P_Hmax , in W.kg⁻¹)
215 can be expressed as:

$$216 \quad P_Hmax = \frac{F_H0 \cdot v_H0}{4} \quad [13]$$

217

218 And the mechanical F-v profile (S_{Fv}) as :

$$219 \quad S_{Fv} = -\frac{F_H0}{v_H0} \quad [14]$$

220

221 From equations (11) to (14): v_Hmax and τ can be expressed as functions of P_Hmax and S_{Fv} :

$$222 \quad v_Hmax = \frac{2\sqrt{-P_Hmax \cdot S_{Fv}}}{2 \cdot k \cdot \sqrt{\frac{P_Hmax}{-S_{Fv}} - S_{Fv}}} \quad [15]$$

$$223 \quad \tau = \frac{1}{2.k.\sqrt{\frac{P_Hmax}{-S_{Fv}}}-S_{Fv}} \quad [16]$$

224

225 Sprinting acceleration performance as a function of horizontal force production capacities

226 Linear sprinting acceleration performance can be represented by the distance covered within a
 227 given time (equation (2)), but also, and with a higher practical sense, by the time (T_X) spent to
 228 cover a given distance (X). This can be obtained isolating t in equation (2):

$$229 \quad T_X = \tau.W_0\left(-e^{-\frac{X + \tau.v_Hmax}{\tau.v_Hmax}}\right) + \frac{X + \tau.v_Hmax}{v_Hmax} \quad [17]$$

230 with W_0 the main branch of the Lambert W function defined on real values and respecting
 231 $W_0(0) = 0$ and $W_0(-1/e) = -1$.

232 From equations (15) to (17), T_X can be expressed as function of P_Hmax and S_{Fv} :

$$233 \quad T_X = -\frac{W_0\left(-e^{-\frac{\sigma_2^2 \sigma_1}{2\sqrt{-P_Hmax.S_{Fv}}}}\right)}{\sigma_2} - \frac{\sigma_2 \sigma_1}{2\sqrt{-P_Hmax.S_{Fv}}} \quad [18]$$

234 where

$$235 \quad \sigma_1 = x + \frac{2\sqrt{-P_Hmax.S_{Fv}}}{\sigma_2^2} \quad [19]$$

$$236 \quad \sigma_2 = S_{Fv} - 2k\sqrt{-\frac{P_Hmax}{S_{Fv}}} \quad [20]$$

237

238 **METHODS USED FOR MODEL SIMULATION**

239 **F-v relationship regression model**

240 Sprinting F-v relationship has been hitherto experimentally described by a linear regression
 241 ^{8,9,20}. Equation (7) shows here that, when velocity–time curve during a sprint acceleration is
 242 described by a mono-exponential function (equation (1)) ^{20,27}, the F-v relationships follows a
 243 2nd order polynomial function, with a viscosity component associated to aerodynamic
 244 resistance. The Root Mean Square Error (RMSError) in F_H , as well as the differences in F_H0
 245 and v_H0 , between values obtained by the 2nd order polynomial function (equation (7), (8) and
 246 (10)) and values obtained by a linear regression fitting of the values obtained by this polynomial
 247 function, were computed on different simulated sprints characterizing individuals with different
 248 k (from 0.0025 to 0.0044 N.s².m⁻².kg⁻¹, increment step of 0.0001), v_Hmax (from 5 to 12 m.s⁻¹,
 249 increment step of 1) and τ (from 0.8 to 1.5 s, increment step of 0.1) values.

250

251 **Effect of P_Hmax and S_{Fv} on sprint acceleration performance**

252 The relative influences of P_Hmax and S_{Fv} on sprint acceleration performance (T_X) were
253 analysed via simulation of equation (18) for different sprint distances (X from 5 to 30 m,
254 increment step of 5). For that, T_X changes with S_{Fv} were determined for different P_Hmax
255 values and for different X values. The range of P_Hmax and S_{Fv} values used in the simulations
256 correspond to those previously reported for humans : P_Hmax from 10 to 30 W.kg⁻¹ (increment
257 step of 2) and S_{Fv} from -1.5 to -0.038 N.s.m⁻¹.kg⁻¹ (increment step of 0.006)^{20,21,30}. In case of
258 a curvilinear change in T_X with S_{Fv} at a given P_Hmax and for a given sprint distance X (as
259 observed during ballistic push-off,¹²), the S_{Fv} values associated to the minimum T_X value (and
260 so the best acceleration performance), corresponding to an “optimal” sprinting F-v profile
261 ($S_{Fv}OPT$), were determined for different sprinting distances (X) and P_Hmax values. The
262 respective effects of P_Hmax and X on $S_{Fv}OPT$ were then studied.

263

264 **METHODS USED FOR MODEL APPLICATION TO EXPERIMENTAL DATA**

265 The relative influences of maximal power output and mechanical F-v profile on sprint
266 acceleration performance (T_X) theoretically assessed by the model simulation were then tested
267 on experimental data to quantify their respective contributions to explain inter-individual
268 differences in acceleration performance over different distances of athletes from different
269 sports.

270

271 **Subjects, experimental protocol and measurements**

272 After giving their written informed consent, 231 athletes (144 men and 87 women, their mass,
273 stature and body mass are presented in Table 1) from various sport disciplines volunteered to
274 participated in this study, which was approved by the local ethical committee of the Catholic
275 University of San Antonio (Murcia) in agreement with the Declaration of Helsinki (more details
276 in³⁰. The sport disciplines were chosen to potentially cover a large spectrum of different
277 horizontal force production capacities regarding the importance and type of sprint acceleration
278 within each discipline: track-and-field sprinters (~30-50m sprint accelerations), soccer players
279 (5-30m sprint accelerations without important strength training habits), rugby players (5-30m
280 sprint accelerations with strength training habits), basketball players (5-10m sprint
281 accelerations and ballistic actions) and weightlifters (no sprint acceleration but high strength
282 training habits). After a complete warm-up (jogging and joint mobility exercises followed by
283 three progressive sprints of 30–40 m at increasing running velocities), athletes performed two

284 or three all-out 40-m sprints (separated by >10 min) from a crouched position (staggered-
285 stance), the fastest trial being considered for further analyses. During each trial, athlete's
286 instantaneous velocity was measured at a sampling rate of 46.875 Hz with a radar system
287 (Stalker ATS System, Radar Sales, Minneapolis MN, USA) placed on a tripod 10 m behind the
288 subjects at a height of 1 m. All data were collected using STATS software (Model: Stalker ATS
289 II Version 5.0.2.1, Applied Concepts, Dallas, TX, USA) provided by the radar device
290 manufacturer.

291

292 **Data analyses**

293 Individual force- and power-velocity relationships in sprinting were assessed as described in
294 previous studies (details in Samozino et al 2016, Morin et al 2019). Briefly, for each trial,
295 velocity-time curve was fitting using equation 1 (with a time delay as described in Morin et al
296 2019) and least-square regression method to determine individual v_Hmax and τ values. From
297 the latter and equations (3) to (5), F_H and the associated power output in the horizontal direction
298 were computed at each instant to determine individual force- and power-velocity relationships
299 in sprinting, and associated F_H0 , v_H0 , P_Hmax and S_{Fv} values. Using equation (2), split times
300 at 5, 10, 15, 20 and 30 m were computed. If the effect of S_{Fv} on sprint acceleration performance
301 was observed as curvilinear, as supposed here from what occurs in jumping¹², the optimal S_{Fv}
302 (S_{FvOPT}) was computed for each athlete and each sprint distance simulating equation (18) using
303 individual k and P_Hmax values. Then, the actual athlete's S_{Fv} value was expressed in
304 percentage of S_{FvOPT} of each sprint distance, and the F-v difference between S_{Fv} and S_{FvOPT}
305 (Fv_{diff} , in %) was computed as:

$$306 \quad Fv_{diff} = 100. \left| 1 - \frac{S_{Fv}}{S_{Fvopt}} \right| \quad [21]$$

307 **Statistical analyses**

308 All data are presented as mean \pm standard deviation (SD). If S_{FvOPT} existed, the respective
309 contributions of P_Hmax and Fv_{diff} (independent variables) to explain inter-individual
310 variability in acceleration performance (dependent variable) were assessed using stepwise
311 multiple regression analyses (standardised β , F , R^2 change [per variable], and model R^2
312 [adjusted], p) performed separately for the different sprint distances (5, 10, 15, 20 and 30 m) on
313 all data pooled together. P_Hmax and Fv_{diff} at the different sprint distances originally violated
314 the assumption of distribution normality and were then log- and square-root-transformed,

315 respectively. Note that if $S_{Fv}OPT$ did not exist, S_{Fv} was used in the multiple regression analysis
316 instead of Fv_{diff} .

317

318 RESULTS

319

320

321 MODEL SIMULATION

322 For sprint acceleration performances simulated for individuals with different values of k (from
323 0.2 to 0.35), v_{Hmax} (from 5 to 12 m.s⁻¹) and τ (from 0.8 to 1.5 s), the RMSError in F_H over the
324 entire F-v relationship between values modelled by the 2nd order polynomial function and
325 values obtained by a linear regression were from 0.382 to 4.50 N (i.e. from 0.005 to 0.056 N.kg⁻¹,
326 figure 1A, B). The associated differences in F_{H0} and v_{H0} were from -10.05 to -0.848 N (i.e.
327 from -0.123 to -0.01 N.kg⁻¹), and from -0.206 and -0.009 m.s⁻¹, respectively (Figure 1C, D).

328

329 *** INSERT FIGURE 1 ABOUT HERE ***

330

331 As expected, P_Hmax positively affects sprint acceleration performance, as illustrated in Figure
332 2B with a decrease in sprint acceleration time when P_Hmax increases, whatever the F-v profile.
333 The main original result was the curvilinear changes in sprint acceleration time with F-v profile
334 for a given P_Hmax and sprint distance (Figure 2A, B). Such variations support the existence
335 of an optimal S_{Fv} ($S_{Fv}OPT$) minimising the sprint time (and so maximising sprint acceleration
336 performance) for given P_Hmax and sprint distance. Moreover, $S_{Fv}OPT$ values change
337 according to both P_Hmax and sprint distance values: $S_{Fv}OPT$ values tend to velocity-oriented
338 F-v profiles when sprint distance increases or when P_Hmax decreases (Figure 3).

339

340 *** INSERT FIGURES 2 and 3 ABOUT HERE ***

341

342 MODEL APPLICATION TO EXPERIMENTAL DATA

343 As initially expected, athlete's P_Hmax , F-v profile and sprint acceleration times at different
344 sprint distances were very different across sport activities (Table 1). Figure 4 presents the
345 individual F-v profiles expressed relatively to the optimal one for each sprint distance and each
346 sport activity. Modelled and actual sprint acceleration performances are presented in Figure 5

347 (and associated videos presented in supplementary materials) to illustrate the respective effects
348 of P_Hmax and F-v profile on acceleration performance over different sprint distances of male
349 and female athletes from different sports. Figures 4 and 5 show that the variability in $S_{Fv}OPT$
350 across sprint distances (whatever P_Hmax) is larger than the inter-individual variability in F-v
351 profile. For all sprint distances, multiple regression analyses showed that both P_Hmax and
352 Fv_{diff} significantly contributed to sprint acceleration performances and explained their quasi-
353 entire variance ($R^2 > 0.99$, Table 2). For the different sprint distances, the variances in
354 performance (time to cover the distance) were mainly explained by P_Hmax (R^2 change from
355 0.92 to 0.99) with a high sensitivity (standardised β from -0.88 to 1.05). Yet significant and
356 non-negligible, the part of the explained variance of Fv_{diff} in sprint performance (R^2 change
357 from 0.004 to 0.063), as well as its weight to predict sprint performance (standardised β from
358 0.06 to 0.26), are lower.

359 *** INSERT TABLES 1 and 2 ABOUT HERE ***

360 *** INSERT FIGURES 4 and 5 ABOUT HERE ***

361

362 **DISCUSSION**

363 The main finding of this study is that sprint acceleration performance over short distances (<30
364 m) depends on both maximal horizontal power output (P_Hmax) and individual F-v profile, with
365 the existence of an individual optimal F-v profile corresponding to the best balance between
366 horizontal force and velocity capacities. This optimal profile, which can be accurately
367 determined for each individual by numerical simulation, depends on maximal power output and
368 sprint distance. The validity of the macroscopic biomechanical model of sprint acceleration
369 performance on which these findings were based was supported by very low errors between
370 modelled and measured values. When applying this model to the data of 231 male and female
371 athletes from very different sports, differences between optimal and actual F-v profile (Fv_{diff})
372 were observed and depend more on sprint distance than on individual F-v profile. For a given
373 sprint distance, acceleration performance (<30 m) mainly depends on P_Hmax and slightly on
374 Fv_{diff} , the weight of each variable changing regarding sprint distance.

375

376 **The biomechanical model**

377 These results are based on a macroscopic biomechanical model using an inverse dynamics
378 approach applied to the athlete's body CoM during linear sprint running acceleration. Based on

379 the commonly used mono-exponential model of the CoM kinematics during an all-out running
380 acceleration, this approach models the net step-averaged external force the runner develops onto
381 the ground in the horizontal antero-posterior direction, as well as the associated power output.
382 Note that this power output (named ‘horizontal power output’ for simplicity ³¹) corresponds
383 here to the rate of the mechanical work only associated to the net step-averaged horizontal
384 component of the external force, i.e. associated to i) the step-to-step change in mechanical
385 kinetic energy of the CoM in the horizontal antero-posterior direction and ii) to the work
386 performed against air friction. Because it aims at studying step-to-step athlete’s acceleration
387 capacities, this model focuses on step-averaged external horizontal force production and not on
388 within-step changes in external force nor on the total external power generated by muscles
389 including the internal power to accelerate the segments with respect to CoM ³². Moreover, this
390 approach does not focus on the several underpinning mechanisms, such as muscle architecture,
391 neuromuscular function, movement pattern, running kinematics (contact time, step rate/length)
392 or other motor behaviours involved in sprint performance. The latter are not neglected within
393 this macroscopic model, but they are encompassed by the different parameters associated to the
394 model, provided they affect external horizontal force production. The main other simplifying
395 assumptions of this model are those inherent to the application of fundamental laws of dynamics
396 to the whole human body considered as a system represented by its CoM ^{4,12,20}, and the
397 estimation of the horizontal aerodynamic drag from only stature, body mass and a fixed drag
398 coefficient ²⁸. The high concurrent validity and reliability of such a model to estimate step-
399 averaged external horizontal force and power output values have been recently supported
400 through comparisons to reference force plate measurements during overground sprinting ^{9,20}.

401 Although F-v relationships in sprinting have been experimentally described as strongly linear
402 ^{8,9,13,20,29}, the present biomechanical model showed that, when the velocity-time curve is
403 modelled by a mono-exponential regression during an all-out sprint acceleration ^{20,27}, the
404 horizontal force developed onto the ground changes with velocity following a 2nd order
405 polynomial function due to aerodynamic friction force. However, model simulations, covering
406 the entire range of k , v_{Hmax} and τ values characterizing typical human sprint accelerations,
407 showed very low and negligible differences in F_H , v_H0 and F_H0 between linear and polynomial
408 models. Note that the extreme, yet very low, error values reported here were obtained for a
409 sprint simulated for an individual gathering extreme characteristics: 2-m tall, 110-kg individual
410 who reaches 12 m.s⁻¹ with a time constant of 1.5 s. These results support the practical validity
411 and relevance of using linear regressions to describe F-v relationship in human sprint running
412 acceleration, as well as the simplifying assumption made for equation (13) and following ones.

413 That said, it cannot be ruled out that the F-v relationship is actually linear, which would
414 challenge the mono-exponential model used here to describe velocity-time curve during sprint
415 acceleration. In both cases, the differences between models are largely lower than the
416 measurement noise for human performances.

417 The validity of the proposed biomechanical model was tested comparing the acceleration times
418 measured using a laser device to times estimated using equation (18) with, as input data,
419 individual P_Hmax and F-v profiles measured by force plates (see Supplementary Material). The
420 results showed no differences between predicted and measured values, associated to a low
421 systematic (<0.4%) and random (<3.5 %) errors. These low differences were within the range
422 of measurement noise previously reported for different sprint time or force-velocity relationship
423 variables ^{20,33,34}, and showed that the errors induced by the above-mentioned simplifying
424 assumptions are very low. Therefore, sprint acceleration times (< 30 m) can be accurately
425 predicted using the proposed model from individual P_Hmax , F-v profiles and k values.

426

427 **Horizontal force production capacities and sprint acceleration performance**

428 Sprint acceleration performance over short distances (< 30 m), considered here as the time
429 required to cover a given distance, was shown to depend on both the maximal power output
430 developed in the horizontal direction (P_Hmax) and the F-v profile (S_{Fv}), as previously reported
431 for acyclic ballistic push-off ¹². This was supported here by numerical simulation of the model,
432 but also from regression analyses on more than 230 athletes from different sports. Even if their
433 respective magnitude of influence on sprint acceleration performance changes with the value
434 of one another and with the sprint distance, simulations of the model (figure 2) showed that
435 P_Hmax has overall the greatest weight. From a purely mechanical point of view and from
436 previous experimental studies ^{8,18,19}, sprint acceleration performance (whatever the distance) is
437 directly related to the average horizontal power output produced over the entire targeted
438 distance. As expected, the model simulation results confirmed that this largely depends on
439 P_Hmax , which is a macroscopic index informing on horizontal force production capacities over
440 the entire spectrum of velocities (i.e. related to a shift of the F-v relationship upwards and to
441 the right). When investigating in more details the horizontal force production abilities, sprint
442 acceleration performance, and in turn average power output produced over the entire
443 acceleration distance, also depends on F-v profile, that is the ratio between horizontal force
444 production capacities at low (F_H0) and high (v_H0) velocities (i.e., the slope of the F-v
445 relationship). For each individual, characterized by both P_Hmax and k values, and for each
446 sprint distance, a sprint optimal F-v profile (S_{FvOPT}) exists that represents the best balance

447 between F_{H0} and v_{H0} (i.e. the best F-v relationship slope) maximizing acceleration
448 performance (and so minimizing sprint times). This optimal F-v profile allows one athlete to
449 stay the closest as possible of his/her optimal velocity over the entire acceleration phase,
450 corresponding to horizontal power output within the upper part of the parabolic P-v relationship
451 (Figure 6). The average horizontal power output produced over the entire acceleration phase is
452 then maximised and the acceleration time minimized. Another athlete, with the same P_{Hmax} ,
453 but presenting a non-optimal F-v profile too much oriented towards F_{H0} and not enough
454 towards v_{H0} (i.e. too 'steep' F-v relationship) would produce power output mostly on the
455 descending part of his P-v relationship (Figure 6), and vice versa for an athlete presenting a
456 non-optimal F-v profile not enough oriented towards F_{H0} (i.e. too 'flat' F-v relationship). For
457 the latter cases, the average horizontal power output produced over the acceleration phase
458 would be reduced, and so would performance. Note that in the typical example presented in
459 Figure 6, the performance difference between the two athletes at 20 m is ~ 0.1 s (or ~ 80 cm),
460 which represents a meaningful advantage in team sports.

461
462 Obviously, besides being influenced by P_{Hmax} values, the optimal F-v profile value mostly
463 changes with sprint distance: the lower the sprint distance, the more S_{FvOPT} oriented towards
464 force capabilities (F_{H0}) and vice versa. The present approach brings insights about the optimal
465 F-v profile values between these two extreme sprints situations and to what extent they may
466 affect sprint acceleration performance. Note that the effect of sprint distance on S_{FvOPT} is
467 important for short sprint distances (until ~ 15 m, Figure 3), which represent the most common
468 sprint acceleration distances in many sport activities, except in track-and-field sprinting events.
469 Concerning these short sprint accelerations (< 15 m), although the effect of F-v profile on sprint
470 performance may seem to be low in absolute values (Figure 2A), this effect is quite important
471 when considering relative changes (from ~ 10 to 20%). Moreover, for short distance
472 accelerations in numerous sport activities, the aim of sprint acceleration is not to largely
473 outdistance the opponent, but only to take advantage over the very first seconds. For longer
474 sprint accelerations (> 15 m), S_{FvOPT} values correspond to the upper part of the range of S_{Fv}
475 human values oriented towards velocity capacities. This explains why sprint acceleration
476 performance, mostly studied on relatively long sprint accelerations (40-m to 100-m times, 4-s
477 distance), was previously only related to P_{Hmax} and v_{H0} ^{8,18,19,22}. For shorter distance
478 accelerations (5 to 15 m), F_{H0} presents more importance through notably, as shown here, an
479 optimal balance between F_{H0} and v_{H0} .

480 When considering actual human F-v profile values presented here and previously reported
481 ^{8,18,19,22,30} ranging from ~ -1.6 to -0.4 N.s.m⁻¹.kg⁻¹, differences between actual and optimal F-v
482 profiles (Fv_{diff}) occur, whatever the sprint distance (Table 1, Figures 4 and 5). Multiple
483 regression analyses performed here on ~ 230 athletes showed that sprint acceleration
484 performance depends on both P_Hmax and Fv_{diff} , with contribution weight changing as a
485 function of sprint distance. Overall, for acceleration up to 30 m, sprint performance was largely
486 explained (variance and standardized weight) by P_Hmax and to a lesser extent by Fv_{diff} (i.e.
487 by the fact that the F-v profile is not optimal). For acceleration distances between 10 and 20 m,
488 the weight of Fv_{diff} is very low (explained variance $< 1.5\%$, standardized beta < 0.13). For
489 shorter (< 10 m) or longer (> 20 m) accelerations, the contribution of Fv_{diff} to performance
490 increases with optimal F-v profiles oriented towards F_H0 or v_H0 , respectively.

491 One of the main findings highlighted by the application of the model to experimental data of
492 athletes from very different sports (sprinting, team sports, weightlifting) was that Fv_{diff}
493 depends more on the variability in the optimal F-v profile between sprint distances than on the
494 interindividual variability in F-v profiles, as well illustrated in Figures 4 and 5. For short sprint
495 accelerations ($< \sim 10$ m), all the athletes (from sprinters to weightlifters) present a F-v profile
496 not oriented enough towards F_H0 compared to the optimal F-v profile (i.e. too ‘flat’ F-v
497 relationship, or force deficit). For long sprint accelerations ($> \sim 20$ m), all the athletes tested here
498 (and likely all humans) present a F-v profile not oriented enough towards v_H0 compared to the
499 optimal F-v profile (i.e. too ‘steep’ F-v relationship, or velocity deficit). Concerning
500 intermediate sprint distances (~ 10 to 20 m), F-v profiles are distributed on both sides of the
501 optimal F-v profile, but the weight of Fv_{diff} in acceleration performance over such distances
502 is very low. The larger influence of acceleration distance (compared to the influence of
503 individual F-v profiles) on Fv_{diff} is mainly due to large differences in the optimal F-v profile
504 between different sprint distances which is larger than the substantial interindividual variability
505 in F-v profile rather observed within each sport than between disciplines. This is well illustrated
506 in figure 4 and in line with Haugen et al.’s results obtained on more than ~ 650 elite athletes
507 from 23 different sports³⁵. Note that the interindividual variability in F-v profile observed here
508 (and associated Fv_{diff} values) is quite related to the sample of athletes tested and may be
509 slightly different with other athletes, notably elite ones.

510

511 **Force-velocity profile and sprint performance optimization.**

512 When a training program is designed to improve sprint acceleration performance, assessing F-
513 v profiles in addition to P_Hmax may help more finely and individually orient training
514 modalities ^{13,21}. Note that both of these variables can be obtained in field conditions using a
515 recently validated method requiring only anthropometric (body mass and stature) and spatio-
516 temporal (split times or instantaneous velocity) parameters ^{9,20}. Values of S_{Fv} make the
517 comparison among athletes possible independently from their power capabilities and their
518 sprint performances (split times at given distances) ²¹, and thus to know whether an athlete, as
519 compared to another one, is characterized by a “force” or a “velocity” sprint profile. The
520 individualization of the training content could hitherto only be done from comparisons to others
521 or to normative values. As previously proposed for ballistic movement ¹², expressing the
522 individual value of S_{Fv} relatively to $S_{Fv}OPT$ for a target sprint distance would allow to quantify
523 to what extent an individual F-v profile is not optimal to take the most advantage of P_Hmax
524 regarding the distance-specific sprint requirements. This can then be used to orient training
525 modalities for a given athlete according to their own strengths and weaknesses, movement
526 specificities and sport context. The present results showed that improving sprint acceleration
527 performance may be achieved through increasing power capabilities (i.e. shifting F-v
528 relationship upwards and to the right) and shifting the F-v profile as close to the optimal one as
529 possible. In case of a ‘force deficit’ (i.e. F-v profile not oriented enough towards F_H0 compared
530 to the optimal one, $S_{Fv} < 100\% S_{Fv}OPT$), force production capacities at low velocity should be
531 trained in priority to increase P_Hmax , and vice versa in case of ‘velocity deficit’ ($S_{Fv} > 100\%$
532 $S_{Fv}OPT$). The magnitude of priority can be given by the value of Fv_{diff} (i.e. the difference
533 between S_{Fv} and $S_{Fv}OPT$): the higher Fv_{diff} (i.e. S_{Fv} largely lower or higher than 100%
534 $S_{Fv}OPT$), the higher the interest to both optimize the F-v profile and increase P_Hmax . Since
535 the variability in $S_{Fv}OPT$ across acceleration distances is higher than the inter-individual
536 variability in F-v profile, sprint acceleration training should be individualized rather by
537 considering the target distance over which the acceleration performance should be maximized
538 than considering the individual F-v profile, as previously suggested and shown for jumping
539 ^{21,36}. Even if in some sports or codes (e.g. team sports) it can be quite complex to define only
540 one training-targeted acceleration distance, the present findings can give some overall insights
541 about how (and with what level of priority) to orient sprint acceleration training content
542 regarding acceleration distances mainly occurring for a given athlete: increasing P_Hmax
543 through F_H0 improvement if short sprint accelerations are targeted ($< \sim 10$ m), through v_H0

544 improvement for long accelerations ($> \sim 20\text{m}$) or through training horizontal force production
545 capacities over the entire velocity spectrum for acceleration distances between 10 and 20 m.
546 Moreover, the biomechanical model used here makes possible, for a given athlete, to estimate
547 the potential gains in acceleration performance associated to an improvement in power
548 capabilities or to a change in F-v profile. This prediction could help coaches to prioritize
549 training towards the one or the other of these two targets. Such changes in the sprint F-v
550 relationship, notably in its slope, may be achieved by specific training focusing rather on F_H0
551 or v_H0 . The latter are very different since they refer to opposite training modalities associated
552 to different movement velocities, force to produce, body positions or segment configurations.
553 For instance, heavy resisted sled training represents a specific means of providing overload to
554 horizontal force production capacities to increase the training exposure to high force-low
555 velocity conditions, which was clearly shown to increase F_H0 and P_Hmax with trivial effect on
556 v_H0 ^{37,38}. Contrastingly, although less studied, training horizontal force production specifically
557 at very high velocities could be performed during maximal speed sprinting or over speed
558 conditions, and should improve v_H0 ³⁹. It is worth noting that at high running speed, there is an
559 interplay between horizontal and vertical force production capacities: the higher the running
560 speed, the more the athlete have to produce high vertical force onto the ground to limit the
561 contact duration and the associated braking impulse ^{6,23}. This double target lower limb should
562 face during the support phase in the late acceleration (high forces in both horizontal and vertical
563 direction) could also contribute to the difficulty to keep producing net backward horizontal
564 force at very high velocities, which was partly shown by the decrease in the ability to orient
565 effectively the force produced onto the ground when velocity increases ^{8,18,19,23}.

566 In both F_H0 - and v_H0 -oriented training based on previous considerations, it is likely that both
567 P_Hmax will increase and S_{Fv} will be optimized (i.e. change towards $S_{Fv}OPT$). These two
568 changes would both result in a higher sprint acceleration performance, as recently shown for
569 jumping ³⁶. Note that the initial level of horizontal force production properties influences the
570 degree of mechanical response when training at different ends of the F-v spectrum, which
571 should be also considered by practitioners to optimize the individual effectiveness of resisted
572 and assisted sprint training ³⁹. Contrastingly, an improvement in P_Hmax associated to a F-v
573 profile even less optimal could induce no gain, if not an alteration, in sprint acceleration
574 performance. Among other experimental reasons, this could partly explain the results of
575 Rakovic et al. ⁴⁰ showing that individualized sprint-training based on F-v profile was no more
576 effective in improving sprint performance than a generalized sprint-training program. The
577 training individualization was performed based on individual F-v profile compared to group

578 values. Since the S_{Fv} group mean was $-0.90 \pm 0.06 \text{ N.s.m}^{-1}.\text{kg}^{-1}$ and the target sprint distance
579 was 30 m, one can reasonably consider, regarding the present results, that all the subjects
580 presented a non-optimal F-v profile towards a v_H0 deficit, and so individualized training
581 interventions may have increased the difference with the optimal F-v profile for numerous
582 subjects. Therefore, yet the weight of F-v profile in acceleration performance is lower than the
583 one of maximal power, considering the optimal F-v profile associated to the target sprint
584 distance could have helped to better individualize training and provided better sprinting
585 performances.

586

587 **PERSPECTIVES**

588 Horizontal force-velocity relationship during sprinting has been shown to be insightful for
589 training sprint propulsion abilities²¹. A simple field method, requiring only spatio-temporal and
590 anthropometrical data, was proposed some years ago to assess horizontal force-velocity-power
591 profile during sprinting with a high concurrent validity compared to force plate
592 measurements^{9,20}, which makes accessible this kind of testing to many athletes and coaches.
593 Once this profile obtained, the remaining question many sport scientists and practitioners have
594 is about how to train this profile in order to improve effectively sprint acceleration performance.
595 The present study brings some answers showing the existence of an individual optimal F-v
596 profile in sprinting which can be used as a training target, as it was shown for jumping^{12,21}.
597 Expressing the individual F-v profile relatively to the optimal one allows to identify the F-v
598 quality to train in priority regarding the distance-specific sprint requirements. This can then be
599 used to orient training modalities to improve the maximal power output while orienting the F-
600 v profile closer to the optimal one by focusing training of horizontal force production at low or
601 high sprinting velocities, or throughout the entire velocity spectrum²¹. Finally, the approach
602 used here is based on macroscopic indices of step-averaged horizontal force production
603 capacities during sprinting. The interactions between these variables and other force
604 components (notably the vertical component), within-step changes in external force and internal
605 mechanical power remain to be further explored to bring insights about the underpinning
606 mechanical determinants of sprinting F-V-P relationship and better understand the transmission
607 efficiency between muscle local function and external mechanical function¹¹.

608

609

610 **CONCLUSION**

611 Based simulations of a biomechanical model presenting a high concurrent validity compared to
612 experimental values and on data measured on 230 athletes from different sports, sprint
613 acceleration performance (over distances < 30 m) was shown to mainly depends on maximal
614 horizontal power capabilities, but also (even to a lesser extent) on F-v mechanical profile
615 characterizing the ratio between maximal horizontal force production at low velocities and
616 horizontal force production capacity at high velocities. For a given maximal horizontal power
617 output, an individual optimal balance between these two capacities exists that maximizes sprint
618 acceleration performance. This sprinting “optimal mechanical F-v profile” changes with the
619 individual maximal horizontal power output, but also and mainly with the sprint distance: the
620 shorter the sprint distance, the more the optimal F-v profile is oriented towards force profile,
621 that is towards maximal horizontal force capacity. Consequently, differences between optimal
622 and actual F-v profile are observed and depend more on sprint distance than on individual F-v
623 profile. For a given sprint distance (< 30 m), the differences in acceleration performance
624 between athletes mainly depends on differences in maximal power capacities and slightly in
625 difference magnitude between actual and optimal F-v profile, the weight of each of them
626 changing with sprint distances. These findings have direct practical applications for sport
627 performance optimization to individualize sprint acceleration training regarding the sprint
628 distance on which the performance has to be improved and the athlete’s sprinting F-v profile.

629

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632 and current discussions about the Lambert W mathematical function and the search for the
633 analytical solution of the optimal force-velocity profile.

634

635 **Conflict of Interest**

636 The authors declare that the research was conducted in the absence of any factors that could be
637 construed as a potential conflict of interest.

638 **Availability of materials and data**

639 The datasets generated by model simulations and analysed during the current study are available
640 from the corresponding author on reasonable request

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739 **TABLES**

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743 **Table 1:** Mean \pm SD of the body mass, maximal horizontal power output and F-v profile, as well as the acceleration time for different sprint distances.

	n	Stature (m)	Body mass (kg)	P_{Hmax} (W.kg ⁻¹)	$F-v$ profile (N.s.m ⁻¹ .kg ⁻¹)	Sprint Time (s)				
						5 m	10 m	15 m	20 m	30 m
Sprint	28	1.72 \pm 0.08	63 \pm 9.8	18.4 \pm 3.05	-0.79 \pm 0.08	1.37 \pm 0.070	2.09 \pm 0.109	2.73 \pm 0.146	3.32 \pm 0.182	4.46 \pm 0.257
Men	15	1.79 \pm 0.04	70.1 \pm 7.6	20.8 \pm 2.19	-0.79 \pm 0.10	1.32 \pm 0.056	2.01 \pm 0.078	2.61 \pm 0.094	3.18 \pm 0.108	4.25 \pm 0.134
Women	13	1.65 \pm 0.05	54.9 \pm 3.8	15.8 \pm 0.91	-0.79 \pm 0.06	1.42 \pm 0.030	2.19 \pm 0.043	2.86 \pm 0.055	3.49 \pm 0.069	4.71 \pm 0.099
Soccer	106	1.74 \pm 0.09	69.6 \pm 11.6	14.8 \pm 2.22	-0.79 \pm 0.08	1.46 \pm 0.067	2.24 \pm 0.108	2.93 \pm 0.150	3.58 \pm 0.194	4.84 \pm 0.287
Men	72	1.79 \pm 0.06	75.4 \pm 8.6	15.8 \pm 1.78	-0.78 \pm 0.07	1.43 \pm 0.055	2.19 \pm 0.082	2.86 \pm 0.106	3.48 \pm 0.131	4.69 \pm 0.182
Women	34	1.64 \pm 0.07	57.4 \pm 6.1	12.6 \pm 1.27	-0.83 \pm 0.08	1.52 \pm 0.047	2.35 \pm 0.073	3.09 \pm 0.100	3.79 \pm 0.129	5.16 \pm 0.193
Basket ball	45	1.86 \pm 0.10	77.7 \pm 12.9	13.3 \pm 2.39	-0.84 \pm 0.12	1.5 \pm 0.094	2.32 \pm 0.149	3.05 \pm 0.204	3.74 \pm 0.262	5.09 \pm 0.388
Men	28	1.92 \pm 0.08	82.9 \pm 12.7	14.5 \pm 1.78	-0.81 \pm 0.13	1.46 \pm 0.084	2.25 \pm 0.112	2.94 \pm 0.13	3.60 \pm 0.144	4.87 \pm 0.168
Women	17	1.77 \pm 0.05	69.3 \pm 7.9	11.4 \pm 1.93	-0.88 \pm 0.09	1.56 \pm 0.078	2.43 \pm 0.132	3.22 \pm 0.188	3.98 \pm 0.248	5.45 \pm 0.375
Rugby	35	1.77 \pm 0.1	87.1 \pm 19.1	16.9 \pm 3.19	-0.97 \pm 0.11	1.37 \pm 0.088	2.13 \pm 0.134	2.82 \pm 0.173	3.47 \pm 0.211	4.74 \pm 0.286
Men	20	1.84 \pm 0.07	102 \pm 9.8	19.1 \pm 2.35	-1.02 \pm 0.12	1.31 \pm 0.061	2.04 \pm 0.086	2.69 \pm 0.105	3.31 \pm 0.122	4.52 \pm 0.155
Women	15	1.68 \pm 0.05	67.4 \pm 5.3	13.9 \pm 1.04	-0.91 \pm 0.05	1.45 \pm 0.036	2.26 \pm 0.054	2.98 \pm 0.072	3.67 \pm 0.09	5.02 \pm 0.128
Weightlifting	17	1.72 \pm 0.07	76.4 \pm 11.2	13.5 \pm 1.67	-0.97 \pm 0.05	1.46 \pm 0.055	2.29 \pm 0.092	3.03 \pm 0.129	3.75 \pm 0.168	5.16 \pm 0.248
Men	9	1.76 \pm 0.06	84.4 \pm 8.9	14.4 \pm 1.75	-0.98 \pm 0.06	1.43 \pm 0.056	2.24 \pm 0.093	2.96 \pm 0.132	3.66 \pm 0.171	5.03 \pm 0.255
Women	8	1.66 \pm 0.02	67.4 \pm 4.4	12.4 \pm 0.70	-0.96 \pm 0.04	1.5 \pm 0.025	2.35 \pm 0.046	3.11 \pm 0.070	3.85 \pm 0.095	5.3 \pm 0.148

Table 2: Stepwise multiple regression analysis results assessing the importance of the maximal horizontal power output (P_{Hmax}) and force-velocity profile (via the difference between actual and optimal F-v profile, Fv_{diff}) to predict sprint acceleration time at 5, 10, 15, 20 and 30 m.

	stand. β	R² change	P-value	F	df	model R²
time@5m				14727	2, 230	0.992
<i>P_{Hmax}</i>	-1.044	0.940	<.001			
<i>Fv_{diff}</i>	0.239	0.052	<.001			
time@10m				21790	2, 230	0.995
<i>P_{Hmax}</i>	-1.010	0.989	<.001			
<i>Fv_{diff}</i>	0.078	0.006	<.001			
time@15m				30906	2, 230	0.996
<i>P_{Hmax}</i>	-0.985	0.992	<.001			
<i>Fv_{diff}</i>	0.060	0.004	<.001			
time@20m				12646	2, 230	0.991
<i>P_{Hmax}</i>	-0.948	0.976	<.001			
<i>Fv_{diff}</i>	0.120	0.015	<.001			
time@30m				11279	2, 230	0.990
<i>P_{Hmax}</i>	-0.889	0.927	<.001			
<i>Fv_{diff}</i>	0.261	0.063	<.001			

stand. β , beta-weight in standardized units; *F*, F value; *df*, degrees of freedom

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748 **FIGURE LEGENDS**

749 **Figure 1:** Linear (grey dash line) and 2nd order polynomial (black line) model to describe Force-
750 velocity relationship of a typical individual: aerodynamic friction coefficient (k) = 0.3, maximal
751 velocity (v_Hmax) = 10 m.s⁻¹ and time constant (τ) = 1.2 s (Panel A). Root Mean Square Error
752 (RMSError) values in horizontal force (B), as well as the differences in maximal theoretical
753 horizontal force (F_H0 , C) and velocity (v_H0 , D) between values obtained by the 2nd order
754 polynomial function and values obtained by the linear regression fitting the values obtained by
755 this polynomial function, for different simulated sprints characterizing individuals with
756 different k (from 0.2 to 0.35), v_Hmax (from 5 to 12 m.s⁻¹) and τ (from 0.8 to 1.5 s).

757
758 **Figure 2:** Changes in sprint acceleration time as function of Force-velocity profile (S_{Fv}) for
759 different sprint distances (5, 10, 15, 20, 25 and 30 m) and a given maximal horizontal power
760 output ($P_Hmax = 20$ W.kg⁻¹, panel A) and different P_Hmax (10, 14, 18, 22, 26 and 30 W.kg⁻¹)
761 and a given sprint distance (15 m, panel B). The grey area represents commonly sprinting F-v
762 profile values previously reported in sport and sciences. The white dots represent the best
763 performances reached at the optimal force-velocity profile for each simulated condition.

764
765 **Figure 3:** Optimal Force-velocity profile according to the sprint acceleration distance for
766 different maximal horizontal power output (P_Hmax , 10, 15, 20, 25 and 30 W.kg⁻¹). The grey
767 area represents commonly sprinting F-v profile values previously reported in sport and sciences.

768
769 **Figure 4:** Force-velocity (F-v) profiles expressed relatively to the optimal profile for each
770 sprint distance and each sport activity. Individual data are presented as jittered dots. The
771 summary of the data is shown as a violin plot reflecting the data distribution, a vertical black
772 bar indicating the median of the data and a horizontal bar indicating the 95% confidence
773 interval determined by bootstrapping.

774
775 **Figure 5:** Modelled sprint acceleration time as a function of F-v profile and maximal
776 horizontal power output (P_Hmax) for different sprint distances. The markers represent
777 experimental acceleration times measured on male and female athletes from different sport
778 activities.

779
780 **Figure 6:** Illustration of horizontal force- and power-velocity relationships of two athletes
781 (panel A) and their horizontal power production and velocity over time during a 20-m sprint

782 acceleration (Panel B). The two athletes present the same maximal horizontal power output
783 with different F-v profile: Athlete 1 (black lines) present an optimal F-v profile ($S_{Fv}OPT$)
784 maximising a 20-m acceleration and Athlete 2 (grey lines) present 'velocity deficit' with a
785 velocity deficit for a 20-m acceleration (i.e. F-v profile not oriented enough towards force
786 production capacities at high velocities). These data are obtained from model simulation (with
787 $k=0.0031$).

788